International Geology Review

Vol. 2, No. 11 November 1960

PARTIAL CONTENTS

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CONTENTS

REFERENCE SECTION

IGR TRANSLITERATION OF RUSSIAN

The AGI Translation Office has adopted the essential features of Cyrillic transliteration recommended by the U. S Department of the Interior, Board on Geographic Names, Washington D. C.

Alphabet		transliteration
А	а	a
Б	б	b
В	в	v
Г	г	g
Д	д	d
Е	е	e, ye (1)
Ё	ё	ë, yë
Ж	ж	zh
З	з	z
И	и	i (2)
Й	й	y
К	к	k
Л	л	l
М	м	m
Н	н	n
О	о	o
П	п	p
Р	р	r
С	с	s
Т	т	t
У	у	u
Ф	ф	f
Х	х	kh
Ц	ц	ts
Ч	ч	ch
Ш	ш	sh
Щ	щ	shch
Ъ	ъ	" (3)
Ы	ы	y
Ь	ь	' (3)
Э	э	e
Ю	ю	yu
Я	я	ya

However, the AGI Translation Office recommends the following modifications:

1. Ye initially, after vowels, and after ъ, ь. Customary usage calls for "ie" in many names, e. g., SOVIET KIEV, DNIEPER, etc.; or "ye", e. g., BYELORUSSIA, where "e" follows consonants. "e" with dieresis in Russian should be given as "yo".
2. Omitted if preceding a "y", for example, Arkhangelsky (not "iy"; not "ii").
3. Generally omitted.

NOTE: Well-known place and personal names that have wide acceptance will be used. Some translations may include elements of previous German transliteration from the Russian; this occurs in IGR most commonly in maps and lists of references. The reader's attention is called to the following variations between German and English systems which may cause confusion when trying to check back to original Russian sources.

German	English
w	v
s	z
ch	kh
tz	ts
tsch	ch
sch	sh
schtsch	shch
ja	ya
ju	yu

TENTATIVE CONTENTS FOR THE DECEMBER 1960 ISSUE

PROBLEM OF THE ORIGIN OF CONTINENTAL GLACIATION[1]

by

L.B. Rukhin

• translated by E. Rukhina •

ABSTRACT

Changes in the flow of the Gulf Stream at the end of the Tertiary producing increased precipita-n, in Arctic areas, combined with the appearance of the Thompson Ridge cutting off warm rth Atlantic waters from the Arctic basin, were contributing factors to the first of the Pleistocene ciations. Periodic opening and closing of the barrier to warm waters during the Pleistocene plain the interglacial epochs. Continental glaciation begins at the periphery of land masses where ecipitation is greatest, not in the high interiors. A greater factor determining continental glacia-n is polar wandering. During the Tertiary the North Pole was in the Pacific Ocean where the ter is so deep that freeze-over could not occur. Evidence from paleomagnetic studies, paleon-ogy and stratigraphy shows that upper Paleozoic glaciation was similarly the result of a com-ation of physico-geographic factors resulting from polar wandering and not continental ift. -- M. Russell.

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Among the more interesting features of the rth's surface today are the glaciers and es-ially the continental glaciers (in Antarctica Greenland). In past periods they some-es spread over large areas and to the low itudes.

The reason for this has not been clear until w in spite of many articles contained in books glaciology (Kalesnik, 1939) and paleoclima-ogy (Brooks, 1952).

Many facts about the two last extensive ciations, Quaternary and upper Paleozoic, ow that continental glaciers are primarily result of some combination of physico-ographical circumstances on the earth's rface, and so for an explanation of their nesis it is not necessary to rely always on ronomical causes.

I

In the Quaternary the continents and the eans were as they are now, with respect to ysico-geographical conditions, therefore, analysis of the conditions in which the gla-tion originated is of great interest.

In the Quaternary the centers of continental ciations were not at the pole, but at some tance from it. The Greenland glacial center s at latitude 75° and the Labrador and Scan-avian glacial centers about 10° to 15° farther uth. The ice edge reached in some cases latitude.

The Quaternary glaciations were in the northern part of the Atlantic ocean. To the west and east the intensity of glaciation decreased. So at the same latitudes in North America, the continental glacier which spread across Labrador and the greatest part of the United States was displaced by the glaciation of the Rocky Mountains. In Eurasia the intensity of glaciation in the direction from the Atlantic ocean diminished so rapidly, that the extreme glacial edge on the Russian Platform was nearly in a north-south direction and the vast Siberian area situated farther north than the Scandinavian glacial center had only mountain glaciers.

The decrease of intensity of glaciation farther from the Atlantic Ocean is known not only from east to west, but also to the north. For example Peary Land was not covered with glaciers during the Quaternary period, in spite of the fact that it was about 1,500 m high (Gerasimov, 1939).

The Gulf stream is a characteristic feature of the Atlantic and those investigators are right who think it had great influence on Quaternary glaciation.

The configuration and intensity of the Gulf stream changed during the Quaternary. At the very end of the Tertiary the Panama isthmus appeared. Its appearance changed the intensity of the Gulf stream as great masses of warm water drifted into the Caribbean Sea, and then these waters joined the Pacific equatorial drifts, but didn't turn to the north as they do now.

The flow of the Gulf stream was also influenced by the barrier stretching between England and Ireland to Greenland, where there is now a submarine ridge. The top of this ridge, which is called the Thompson Ridge is

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anslated from Problema proiskhozhdeniya materi-vykh oledenenii: Izvestiya vsesoyuznogo geogra-heskogo obshchestva, v. 90, no. 1, 1958, p.25-38.

in some places only 200-300 m below sea-level. Somewhat to the north is the Nansen Ridge which passes from Spitsbergen to North Greenland. It is also well expressed in recent bottom topography.

However, in the Pliocene the Thompson Ridge was above sea level (Panor, 1948). It is possible that the Nansen Ridge was also higher than now. Therefore the Gulf stream couldn't penetrate into the Arctic Ocean and partly turned up along the Thompson Ridge to the North American coast and partly went south (fig. 1). If the warm waters of the Gulf stream didn't reach the Arctic Ocean its temperature would be lower and it would be covered with ice and a great refrigerator would be formed upon which there would be located an unstable barometric maximum. The cold winds blowing from this maximum could meet with warm wet masses of Atlantic air coming with the Gulf stream, and cause much rain and especially snow. Snow accumulation on the shores of America and Europe washed by the Gulf stream would produce continental glaciation. As the glacier increased in size, the barometric maximum would spread over a greater area. At the same time the region of intensive snow falls

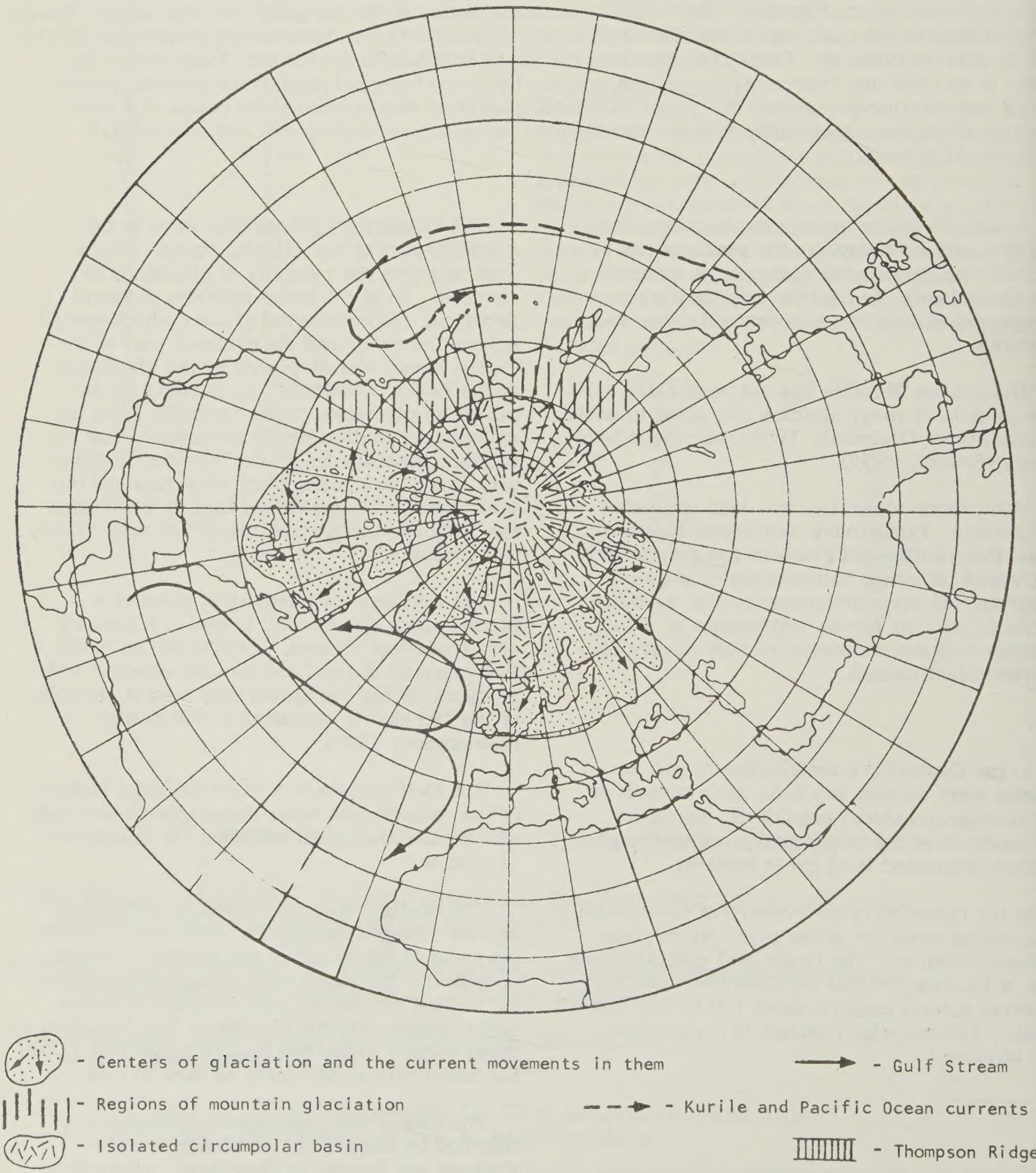


FIGURE 1. Paleogeographical map of the Quaternary ice age

ich were brought from the Atlantic Ocean uld move. So the continental glaciers grew inly from the periphery and not from the nter.

Voeikov, in analyzing the glacial climatic uation, noticed the following difficulties in plaining the origin of great glaciers: 1) even th a moderate slope the middle part of aciers cover would be thicker than the earth's mosphere, 2) such a great continent would too dry, 3) on the open, more or less deep a, there could not be formed a continuous e cover (Voeikov, 1884, p. 158).

Voeikov's first idea is like the supposition Pidoplitshko (n. d.) who thinks that no conental glaciers could exist on plains, for e inclination of their surface is too small to use movements of great ice masses. But ch suggestions are wrong, for the continental aciers grow not from the center, but from e edge.

Voeikov's second idea about the aridity of ntinents which are covered with glaciers is ore valid. But as the growing of the glacier kes place mainly at the edge due to the conensation of moisture brought in great quantis from the neighboring seas it must also be scarded.

The third idea of Voeikov is right only for en seas, for here the water would be mixed the result of water change and currents. If e pole were situated in the middle of an isoted marine basin as happened in the Quaterary, the sea undoubtedly would be frozen and ecome an enormous refrigerator and near it ould accumulate great sheets of ice, if moist arm air came. So one can suppose that the uaternary glaciation on North America and urope had two causes: 1) isolation of the subolar sea as a result of the Thompson Ridge plift or possibly the Nansen barrier; 2) existnce of the Gulf stream and accompanying arm moist air masses on the periphery of the rozen subpolar sea.

If this is true then the question arises: Why id glaciation exist only in the Quaternary and ot in the Tertiary in spite of the existence at hat time of the North Atlantic barrier? On the ontrary, during the Tertiary in the present ubpolar region the climate was much warmer, han now, as indicated by the flora and fauna f that time.

The reason is the displacement of the rotaional axis of the earth.

Climate is determined not only by the latitude ut also by marine currents, the dimensions of he continents and other causes. Therefore the istribution of ancient climate indicators in the eposits of any single period is like an equation with many unknown quantities that make it possible to solve it in many different ways.

When we compare the facts from many periods the influence of the agents which change quickly lose importance. For example, the difference between ancient and modern climatic zones attributed to the influence of ocean currents cannot be, because they changed many times during the three last eras, and so did the dimensions and forms of continents. The climatic changes can be explained by changes in the position of the rotation axis of the earth and the displacement of the poles and the equator.

The investigation of ancient climate is based on the analysis of peculiarities of sedimentary rocks and organisms. It shows that from the Paleozoic in any case, and maybe much earlier (Berg, 1948) there were nearly the same climatic zones on the earth as at present, but they were considerably displaced. But in time the climatic zones came nearer and nearer to their present positions. At the beginning of the Paleozoic the North Pole was in the central part of the Pacific Ocean, and the South Pole - near the southern end of Africa. Therefore the ancient equator at that time in the Atlantic was further North than now and passed through Western Europe.

The sharpest change in the position of the rotational axis took place in the Tertiary when the poles were displaced 40-50^{o}. If we admit that a 50^{o} displacement of the poles took place only in the second half of the Tertiary, then the average velocity of the pole displacement was 1. 2 m per year. Today mostly under the influence of seasonal movement of air masses and other causes, the pole moves along a closed spiral-like curve.

It is supposed that the center of this complete spiral, remains in the same place. This point is named the geographical pole. But argument for the continuous displacement of the present geographical poles is expressed again and again at present. Munk and Revelle (1952) think that during the previous 6 years the North pole was displaced in the direction of Newfoundland by 4. 5 m (that is about 75 cm per year). About the same figure is also given by Gold (1955). The supposed displacement of the North Pole in its direction and velocity coincides very well with conclusions drawn from geologic data.

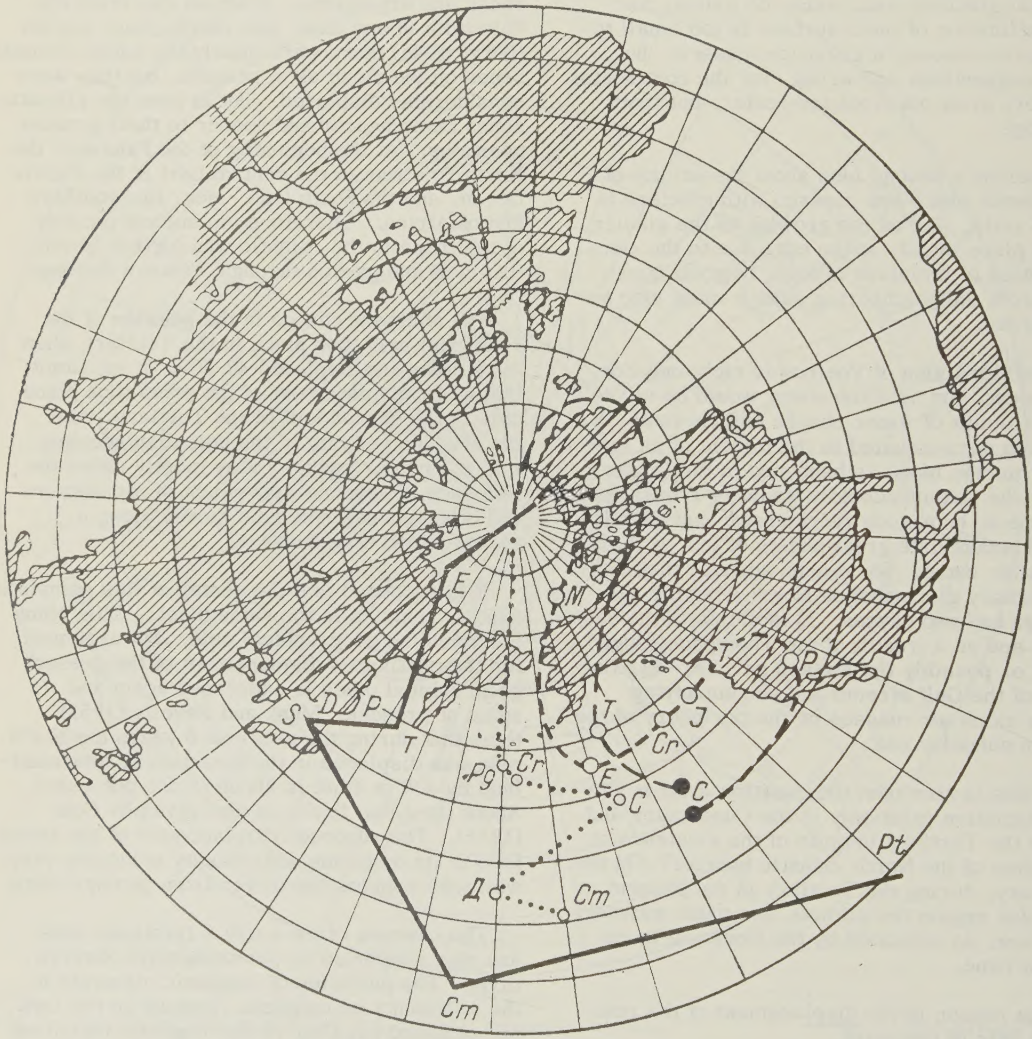
The changes of the earth's rotational axis are also supported by paleomagnetic observations. The particles of magnetic minerals in the sediments or magnetic crystals in the lava are oriented parallel to the magnetic meridian.

Investigation of their orientation makes it possible to define the former position of magnetic poles, and as the magnetic field of the earth depends on its rotation, the displacement of the magnetic poles confirms the changes in

the position of the rotational axis.

All the published results of paleomagnetic observations (Day and Runcorn, 1955; Munk, 1952; XIX Congre's Geol. Intern., 1952) show, that the magnetic pole was situated during the Paleozoic in the Pacific Ocean, that is, in the same place where the geographical North Pole was, judged from the analysis of geologic data. Then it began to move north, and in the second part of the Tertiary the movement had the greatest velocity.

On Figure 2 are shown the paths along which the geographical North Pole moved; they were projected by different investigators and also by the author of the present paper (Rukhin, 1955) based on an analysis of geologic material and on changes in the position of North magnetic Pole according to paleomagnetic measurements. It is interesting to note that the two different methods gave the same results. The cause of the changes in the earth's rotational axis is the redistribution of the earth's masses. To a small extent this redistribution takes place every season because of the ocean and continents warming up in different degrees. Considerably greater displacements of the rotation axis must be caused by the lifting and sinking of great parts of the earth's crust. The redistribution of such great uplifts and subsidences is the main cause of the changes in the position of the



— — - Kreichgauer, 1902 ---- - Rukhin, 1955 •••••• - Koeppen, 1940

▬▬ - Runcorn and Creer, 1955

FIGURE 2. Suggested course of movement of North Pole, according to different investigators

tation axis. The displacement of the poles ces place generally in the same direction, tendency being to place themselves sym- etrically with regard to the existing continents. is balance is not yet reached, for the North le has not arrived at the center of the con- ental hemisphere which is situated between wfoundland and the European coast, where is now to all appearances moving.

Gold (1955) stresses that the displacement the poles is irregular. He supposes that rotation axis of the earth changes its posi- n by fits and starts and the periods of move- ent are comparatively short, not longer than million years. After a period of movement poles are in a stable position for some time if in a trap until strong tectonic movements glaciations displace them again.

Such an idea agrees with the displacement ancient climatic zones; for example, with the pid displacement of the pole at the end of the ertiary as a result of which the North Pole was a basin isolated from the open ocean by the orth Atlantic barrier. Before that time, in ite of equal physico-geographical conditions e isolation of the basin, the existence of the lf stream) there was no glaciation in North merica and Europe, for the pole was still in e northern part of the Pacific Ocean.

The further evolution of glaciation was con- olled by the regime of tectonic movements of e North Atlantic barrier. Its sinking allowed e warm waters to flow into the Arctic basin, hich therefore began to melt. Continental aciers situated near it became smaller or isappeared altogether.

At this time the interglacial epoch began. he next uplift of the North Atlantic barrier opped warm Atlantic waters from entering. he Arctic basin near the pole was frozed once ore, and in the neighborhood of it in the zones f active frontal atmospheric activities in the laces of contact with warmer streams appeared gain great continental glaciers.

In the present epoch the North Atlantic bar- ier has sunk. The warm Atlantic waters enetrate freely into the Arctic basin and warm quickly.

The melting of Quaternary continental laciers did not always proceed evenly. It was reatly retarded in Greenland, which was eparated from the Gulf stream by the wall of he cold East-Greenland current. The present reenland glacier is the great relic of Quater- ary continental glaciers. Its relic nature is onfirmed by the fact that for a considerable istance the coast of Greenland is free of laciers.

Quaternary glaciation on the whole is a good example of one caused by the position of the pole in a basin isolated from the open sea. Other essential factors are the Gulf stream and the activity of the atmosphere in the zone of the entrance of warm air masses accompanying it into the periphery of the frozen subpolar basin.

II

It is much more difficult to reconstruct the paleogeographic conditions of the epoch of the upper Paleozoic glaciation.

In the upper Paleozoic (Lower Gondwanian) deposits of the continents of the southern hemisphere tillites and glacial marine sedi- ments are known in South America (Argentina, South Brazil), in the Falkland Islands, in South Africa, in Madagascar, India, Australia and Tasmania. Almost all glacial deposits are associated with rocks containing only scanty remnants of the Gondwana flora and continental Vertebrata, so it is difficult to determine their age exactly. Shells of marine organisms are rarely found.

Besides this the glacial deposits usually rest with great unconformity on the underlying strata. All of this makes it difficult to determine the age of the glacial series.

The latest materials on the stratigraphy of the Gondwana deposits are printed in a special symposium published for the XIX International Geological Congress (1952). The latest data on the southern part of Australia are to be found in the article by Campana and Wilson (1955).

According to these data the westernmost outcrops of glacial deposits are situated in the central part of Patagonia, where they are found among fossiliferous sediments of Lower and Middle Carboniferous age. In the Upper Carboniferous series glacial facies are entirely absent with the exception of one section. A great number of outcrops of glacial deposits are known in Argentina and South Brazil, but in most cases their exact stratigraphical posi- tion is unknown.

To the south of Buenos Aires marine sand- stones with *Eurydesma* (Harrington, 1955) rest upon the tillites and glacial marine sedi- ments. The presence of this form is very im- portant, because it occurs also in South Africa, India and Australia. The fauna of the *Eurydesma* beds of Argentina and Australia is quite similar. Unhappily this peculiar fauna occurs nowhere beyond the limit of the Gondwana glaciation, so its exact age is unknown.

Another formation which has paleontological remains is the Iraty. It is composed of bitu- minous shales with bones of *Mesosaurus* which are found not only in Argentina but also in South Africa. These are the lowest of the beds

of undoubtedly Lower Permian age. There are no traces of glaciation above them.

In some places in South America glacial deposits rest on polished and striated surfaces of older stones. The number of tillite beds varies from one to five. The glacial deposits are replaced commonly in the upper parts of the outcrop by coal beds which pass into redbeds or even into salt deposits.

The direction of the movement of Carboniferous glaciers in South America is not yet determined. For example in the state of St. Catarina (South Brazil) Salomon-Calvi (1933) thinks that the direction of glacial movement was from east to west. In regions farther to the south (Uruguay) they appear to be from west to east and it seems that in St. Catarina the glaciers moved usually from north-east to south-west (XIX Congrés Geol. Intern., 1952).

Salomon-Calvi thinks that the glaciers in Argentina moved from south to north. Therefore he thinks that there were two ice-centers: one in the southern part of Argentina and the other somewhat to the east of Brazil. In this case the present Paraná basin was already a low region in the Carboniferous and the ice moved in this direction from the south and north-west. Here are to be found most of the marine and glacial-marine sediments that are associated with glacial deposits of this age.

Near South America are the Falkland Islands. The correlation of the glacial deposits which are associated with the beds of analogous genesis in the neighboring continents is difficult, for the latter contain no Eurydesma and Mesosaurus remains. But we have evidence disproving a Carboniferous age for the glaciation. The glacier was moving from south to north, or maybe from southern Argentina or another center situated nearby.

A classical example of the upper Paleozoic glaciation is South Africa. The continental deposits here belong to the Karroo formation. In the most southern region the outcrops are the most complete. The meridional cross section of the Dwyka tillite region is about 100 km and the thickness in the southern part is more than 750 m, excluding the bed of sandstone of non-glacial origin, that lies within the tillite. The thickness of the Dwyka tillite is extremely great, not only as compared to other regions of distribution of upper Paleozoic glaciation, but also as compared to the Quaternary glacial complex.

Another characteristic feature of the Dwyka glacial series is that it has very few varved clays, which shows that the glaciation in South Africa was more extensive than in South America.

The age of the South African glaciation is defined by Du Toit (1954) as Carboniferous. It is possible that the glaciers appeared in the Middle Carboniferous. So in the Cape Mountains Dwyka deposits slowly pass over into the underlying Middle Devonian-Lower Carboniferous Witteberg strata. The upper age limit is indicated by the presence of Lower Permian Mesosaurus in the overlying beds. Only in one part of Southwest Africa there are Eurydesma beds above the tillites, which are overlain by coal deposits and then by beds including Mesosaurus. The direction of the ice movement in South Africa is well known, in general it was from north to south.

Glacial deposits are also known in the equatorial part of Africa. In the eastern part of the Belgian Congo they were described by Boutakoff (1948). The direction of the ice movement was from south to north. So it is possible that the main center of glaciation was somewhere between the equator and South Africa. To the east of Africa tillites are encountered on Madagascar, but they are still not well investigated. Beds with Eurydesma and Mesosaurus have not yet been found.

Upper Paleozoic ice deposits in India which are named Talchir beds, cover a surface of about 1,500 square km. Their thickness varies from 15 to 60 m.

In the Salt Range in Kashmir the Talchir glacial deposits are overlain by sandstones with Eurydesma and other fauna which makes it possible for Indian geologists to correlate them with the Sakmarian. The main glacial center in India was the Aravali Ridge which had at this time mountainous relief. The glaciers that came down from it reached the sea but in the southeastern part the glaciers moved over the land. The Indian glaciation happened only once, for interbedding of till with other deposits has never been found. Another great region of upper Paleozoic glaciation was in Australia and Tasmania.

In Australia the glaciation was the longest. It took place not only in the Carboniferous, but its traces are known in Permian beds. In the middle and especially in the Upper Carboniferous on the present Australian continent there were continental glaciers. But in the Permian beds only a glacial-marine facies is known. Fluvioglacial and lake deposits are known in Carboniferous beds as well as in Permian beds and their number increases to the north and to the west.

Organic remains are also arranged in zones. The Eurydesma fauna, as well as on other continents, is found only in the glacial regions in the southeastern part of Australia (southern part of Queensland, New South Wales, and Tasmania). In western and northern Australia in the Permian marine deposits another complex of forms is found, related to the warm

thys fauna (goniatites, fusulines), which were sent in southeastern Australia.

All these data show that the main glacial nter was situated to the south of the south-stern part of Australia. This direction is licated also by the glacial movement.

When we begin to compare all that was said ove, the peculiarity of the upper Paleozoic acial deposits of the southern continents, we me to several conclusions.

Glaciation begins first in South America d Australia, where together with the glacial posits. Rhacopteris flora was found. Ac-rding to the great thickness of the South rican Dwyka tillites and their gradational ssage into underlying Lower Carboniferous cks, it can be supposed that the Middle rboniferous glaciation was also present in uth Africa.

The extent of the glaciers was greatest in e Upper Carboniferous at the end of which aciers appeared also in India. Permian aciation existed only to the south of Australia.

According to the direction of the ice move-ent and the stratigraphy of glacial deposits the upper Paleozoic in the southern hemi-phere there existed the following ice centers: e South Argentinian, East Brazilian, South frican, Aravali and South Australian. The st was the most permanent.

The most characteristic feature of the acial deposits was the Eurydesma fauna hich is unknown in any other region. The ndemism of this fauna suggests the possibility at a separate sea existed which washed the hores of the southern continents during the me of the upper Paleozoic glaciation. It is ch a closed sea, that is shown on the paleo-eographical maps composed by Furon (1941) nd Umbgrove (1947).

In a preceding paragraph the change in the osition of the rotation axis of the earth was ointed out. For example, the South Pole in he Paleozoic was situated probably in the re-ion of South Africa. The equator also had nother position, it was to the north and not o the south of India. Therefore, all the re-ions of the upper Paleozoic glaciation, con-rary to their present position were situated hainly in the southern hemisphere.

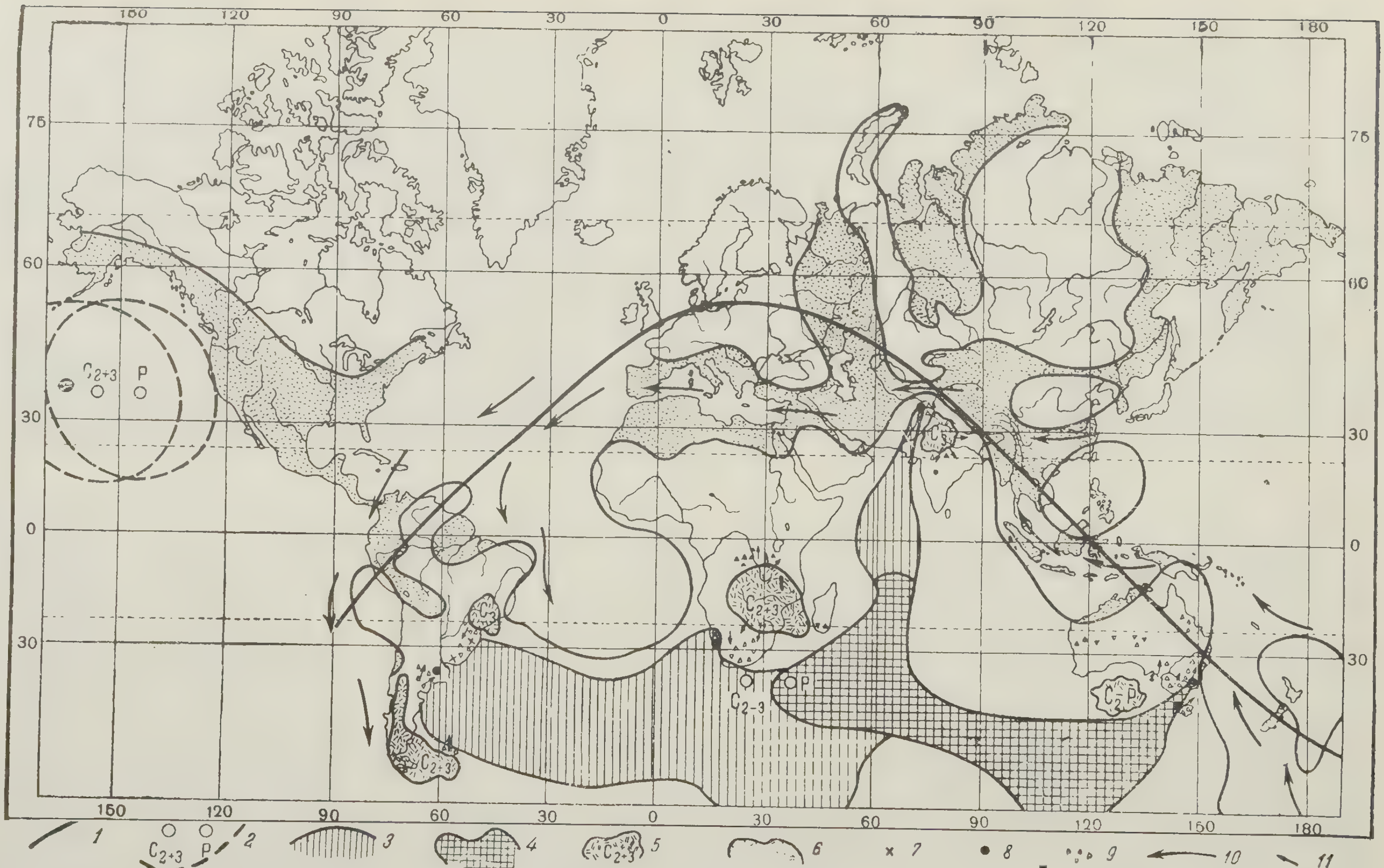
The Gondwana sea, isolated from the open ea in the center of which was the South Pole, must have been getting increasingly colder and ecame a great refrigerator. When the moist ir masses reached the peripheral zones of this ea, just as in the Quaternary glaciation, there ccumulated great masses of snow and then ice. t is natural that such phenomena took place mainly where a great warm current entered the Gondwana sea.

Figure 3 shows a paleogeographical arrange-ment for the upper Paleozoic glacial epoch and it shows the Gondwana sea. It has a three-lobed form. The trade winds and, therefore, currents and the accompanying warm most air masses must have reached the periphery of the Gondwana sea. As a result of their contact with the Gondwana sea snow accumulated through frontal activity of the atmosphere. Naturally at first this process took place on the end of the tongues of the Gondwana sea, which reached into the lower latitudes. At the end of these tongues of the Gondwana sea three glaciation centers were formed: the South Australian, Aravali and South American. They represented polar glaciers which necessarily arose on the periphery of the isolated polar basin. As soon as this isolation disappeared, the glaciers disappeared too and its deposits are overlain by red beds and even salt-rock complexes, in-dicating warm conditions.

The South African glaciation, contrary to that of South America, Australia and India, was polar. But it received moisture from the Gondwana basin which was near by. This caused the displacement of the South African center from the Atlantic Ocean in the direction of the Indian shore; the air masses, which were coming near the western shore of Africa could not bring much moisture, because they had given it off in the Brazilian center of glaciation.

During the Carboniferous and Permian the configuration of the Gondwana subpolar sea changed many times. In the Middle Carbon-iferous the northern tongue did not exist and at that time the cold Gondwana sea spread from South America past South Africa, where the South Pole was situated, to Australia. In the Upper Carboniferous the Gondwana sea had three tongues. In the Lower Permian the dimensions of the Gondwana sea became smaller. Uplifts to the south and east of Madagascar isolated the South American and the Indian parts of the Gondwana basin and maybe made them waterless. There remained only the Austra-lian tongue at the edge of which the North Pole was situated. But it kept the role of a refrig-erator and caused in the Permian the South Australian center of glaciation. But the Per-mian Gondwana basin was not completely isolated. The strait which passed over the present Tasmania and the southeastern part of Australia united it with the tropical sea. Through this strait the cold current carried many icebergs and their melting caused the glacio-marine Permian deposits. The region of land glaciation at that time was entirely situated south of Australia.

The widening of this strait or the formation of others brought a milder climate to the



1-Permo-Carboniferous equator, 2-pole position in Carboniferous and Permian and corresponding 70° latitudes, 3-cold circumpolar basin in Late Carboniferous, 4-cold circumpolar basin in Permian, 5-centers of glaciation and their age, 6-seas, with boundaries of ancient continents, 7- distribution of Mesosaurus, 8-distribution of Eurydesma, 9- area of occurrence of glacial deposits, 10-current directions in the equatorial part of the ocean, 11-direction of movement of continental glaciers.

FIGURE 3. Paleogeographical map of the Late Paleozoic continental glaciation

ndwanian basin, which brought about the appearance of glaciers.

Thus the physico-geographical conditions of origin of the Quaternary and upper Paleozoic ciations have very much in common. The in cause of these glaciations was the existce of the Pole within the limits of a basin lated from the ocean and the presence of werful warm currents on the periphery of s basin. These warm currents stimulated frontal activity of the atmosphere.

The Quaternary and the upper Paleozoic ciations were very much alike, but there e some differences between them. First of , the upper Paleozoic glaciers were closer the equator. This is probably due to the allower depth of the Gondwanian subpolar sin. Other conditions being equal, shallow sins will be covered with a thicker glacial ver which will stretch much farther from e Pole than deep ones, because the cooling water is slowed down when there is great pth near the Pole. Therefore the greater e volume of water, i. e. the greater the pth of basin with a constant area, the less antity of ice will be formed. Therefore, if e Pole is placed in the middle of a deep open ean there will be ice continuous sheet.

The greater the mass of ice in the subpolar sin the sharper its refrigerating influence lower latitudes will be. The appearance ice in the low latitudes lowered the temrature of the air greatly and intensified ontal activity of the atmosphere.

Heavy clouds considerably diminishing the fluence of direct solar radiation were among e factors favoring the appearance of glaciers low latitudes.

III

Wegener's hypothesis of the drifting of connents is often used as an explanation of the ondwana glaciation. One may even come cross the statement that it is the Gondwana aciation that is one of the proofs of this ypothesis.

In reality the study of physico-geographical onditions of the origin of the Gondwana glaciaton just refutes Wegener's ideas. If all connents had been connected in upper Paleozoic me as Wegener suggested, then the existence big glaciers beyond the Pole within this vast ontinent would be excluded because of the dry limate. It is impossible to explain, following Vegener, why the Antarctic had not undergone laciation at all, but Australia continued to ndergo glaciation in Lower Permian time, fter this had ceased in the neighboring connents in the Upper Carboniferous epoch. All nese great difficulties arise as a result of the assumption of direct contact between all southern continents.

Also, Wegener's hypothesis cannot explain the existence of several glacial epochs during the Gondwana glaciation. It is characteristic that Wegener's advocate, Salomon-Calvi, in his book (1933) devoted to upper Paleozoic glaciations was obliged to disjoin the southern continents a little and to remove Antarctica altogether from the pole. The opinion of this author is interesting in that he says that the position of the continents which he suggested can explain only one glaciation, but cannot explain causes of its division into the several glacial epochs separated by extremely long intervals as it may be seen, for instance, in Australia (Salomon-Calvi, 1933). For this reason he is obliged to admit not only drifting of continents, but also astronomical causes of glaciation.

Thus, Wegener's hypothesis alone cannot explain the Gondwana glaciation by which this hypothesis was supported.

More recently the causes of the Quaternary glaciation were explained by the hypothesis of Milankovich. Some new astronomical data (Woerkom, 1953) led to the necessity to revise the radiation curve which had been constructed by Milankovich. The new radiation curve has no great conformity with the course of Quaternary glaciation. It was found further that though the change of the amount of solar radiation obtained by the earth as the result of the change of ecliptic inclination, of the excentricity of the earth's orbit and the position of its perihelion now, it is not sufficient to influence the climatic phenomena on the Earth.

Proceeding from the fact that the epochs of glaciation were concomittant with the periods of mountain building it is often suggested that the vast continental glaciations existed at a considerable height over the level of the sea. But this point of view is not correct. Neither in the Quaternary period, nor in the upper Paleozoic were the main centers of glaciation situated in the uplifted folded regions. As a rule glaciers moved not from young mountains formed by this folding, but on the contrary towards them. In South Africa, for instance, the center of glaciation was not in the Cape Mountains, but to the north of them. The center of glaciation in Australia too, was situated far from the various Cordilleras. The Gondwanian glacial deposits were so well preserved as the result of the fact that the glacier moving in the direction of these uplifted mountain areas reached the sinking marginal basin situated in front of it.

The conclusion suggests itself that not the uplifting of dry mountainous land is the particular cause of glaciation as is often

thought. The plain relief of the greater part of the territory covered by Quaternary glaciation points to it too. The same plain relief is discovered when studying Gondwana glacial deposits. The relief covered by them is not more than 100 or 200 m. The conclusion about mountain glaciation in Upper Carboniferous time applies only with regard to the Belgian Congo, India and the southern most parts of Australia.

The continental type of climate is further characterized by a small amount of atmospheric precipitation as compared to the marine climate and therefore it is not favorable to the accumulation of great masses of ice. In connection with this during the Quaternary glaciation in Siberia no cover of glaciation was formed in spite of lower temperature which existed there. Glaciers are a product of marine climate, because it is a great amount of precipitation that is necessary for their appearance as a result of intensification of frontal activities of the atmosphere. The appearance of great continents with continental climate not only does not stimulate, but on the contrary prevents the appearance of vast polar glaciers on their surfaces.

Therefore, it is necessary to find some other explanation for the existence of a connection between the glaciations and epochs of mountain building. According to the author these epochs are favorable to glaciation because during them partial uplifts of the sea bottom take place. Isthmuses between the continents follow and fully or partially isolated basins form near the poles. They are covered by ice and become cold centers near which masses of ice may accumulate on the neighboring parts of the continents. The accumulation of great masses of ice, however, is possible only in those areas where a great amount of precipitation takes place in connection with the frontal activities of the atmosphere. The warm currents approaching these parts of continents undoubtedly favor these phenomena.

The combination of all these conditions which were necessary for the appearance of continental glaciation were not observed in every epoch of mountain-building. Among the three latest big diastrophisms the Caledonian folding was not accompanied by continental glaciation at all. In the Variscan [Hercynian] period glaciation formed only near the South Pole and in the Alpine [period] only near the North Pole.

Everything said refers only to middle latitude glaciers forming at some distance from the pole. The glaciers near the pole existed probably always, when the poles were situated within sufficiently big continents.

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RUTILE BEARING ECLOGITES FROM THE SHUBINO VILLAGE DEPOSIT IN THE SOUTHERN URALS[1]

by

B.V. Chesnokov

• translated by E.A. Alexandrov and Associates •

ABSTRACT

Rutile-bearing eclogites of titanium ore potential occur in crystalline schists of the M series near Shubino village in the southern Urals. They were formed by metamorphism of high-titanium igneous rocks. Retrogressive metamorphism is exhibited by the eclogites. -- M. Russell.

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In 1936 G. I. Kirichenko described "green garnet-glaucophane schists" which contain a considerable amount of rutile [8]. In the major work on geology of the Orsk-Khalilovo region in 1941 Kirichenko described these rocks again [5]. In the same publication V. M. Sergievsky referred to the above mentioned rocks as typical amphibole-eclogites and also noted the presence of rutile.

Since 1956 the eclogites from the region of Shubino village have been studied by students of the Department of Mineralogy of the Sverdlovsk Mining Institute as ores which could be used after upgrading to a high rutile content.

GEOLOGIC AND PETROGRAPHIC CHARACTERISTICS OF THE DEPOSIT

Ecologite and garnet-glaucophane rocks occur widely as isolated bodies in crystalline schists in an area of 25 sq km, 2 km northwest of Shubino village. The schists constitute the axial part of the metamorphic rocks (M-series) of the Southern Urals [8, 3]. These rocks are graphite-mica-quartzites, quartz-muscovite and garnet-glaucophane-muscovite-quartz schists and are strongly folded. They strike 320-340° NW and dip 50-60° SW.

A great number of eclogite bodies crop out in the area. The largest of these bodies are about one km in strike length and 150-200 m thick. In all of the cases observed by the author the eclogites are conformable with the schistosity of the enclosing rocks. Boudinage structures are common. The dimensions of isolated boudins of eclogites vary from a few decimeters to hundreds of meters. The amount of rutile in the eclogites and garnet-glaucophane schists in most cases does not exceed one or two percent. The eclogites with a low-rutile content are represented by clear green or bluish-gray garnet-omphacite varieties and contain a significant amount of amphiboles (glaucophane and an amphibole close to actinolite in composition). These rocks have a fine-grained groundmass with nematoblastic or fibroblastic texture which makes them quite strong and tough. The garnet-glaucophane schists are less common than eclogites, and their color varies from blue to grayish-blue. The texture of the groundmass is nematoblastic or fibroblastic. However, the rock itself has a porphyroblastic texture. As in the eclogites, porphyroblasts consist of red garnet close to almandite in composition. The amount of garnet in the eclogites and schists is approximately the same, namely, about 20-40 percent. Usually the crystals of garnet reach 2-4 mm in cross section.

Four potential ore bodies have been discovered. The whole deposit is about 60 m thick, with a very gentle westward dip and disappears abruptly at the western flank. Evidently this body is a boudin surrounded by country rocks. These rutile-bearing eclogites are dark-greenish rocks with a slightly banded or roughly schistose to massive texture, and a high specific gravity (about 3. 4). The groundmass of the rock has nematoblastic texture and consists of glaucophane, omphacite, epidote, quartz, muscovite and rutile.

The three following types of rutile-bearing eclogites are more or less definitively distinguished:

Glaucophane eclogites (fig. 1). The groundmass is composed of glaucophane, omphacite and rutile.

Epidote-glaucophane eclogite (fig. 2). The groundmass consists of glaucophane, omphacite, epidote and rutile.

Quartz-muscovite (fig. 3). The groundmass is composed of glaucophane, omphacite, muscovite, quartz, and rutile.

The ore bodies are chiefly in the first two types. The third type is usually developed in

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[1] Translated from Rutilsoderzhashehie eklogity Shubinskogo mestorozhdoniya na Yuzhnom Urale, translated from Izvestiya Vysshikh Uchebnykh Zavedeniy, Geologiya i Razvedka, 1959, no. 4, p. 124-136. Reviewed by E. Ingerson.

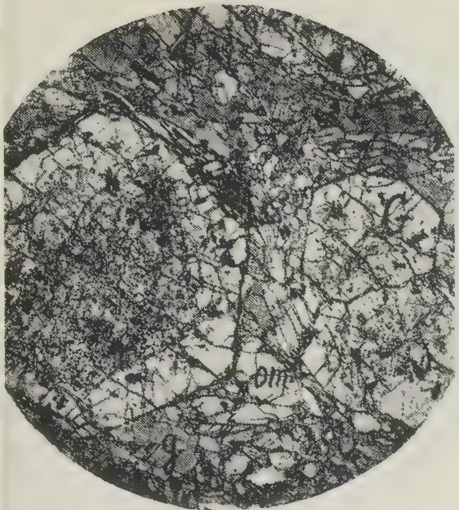

FIGURE 1. Glaucophane eclogite: G-garnet; g-glaucophane; om-omphacite; rutile (black without analyzer); diam. d=6 mm

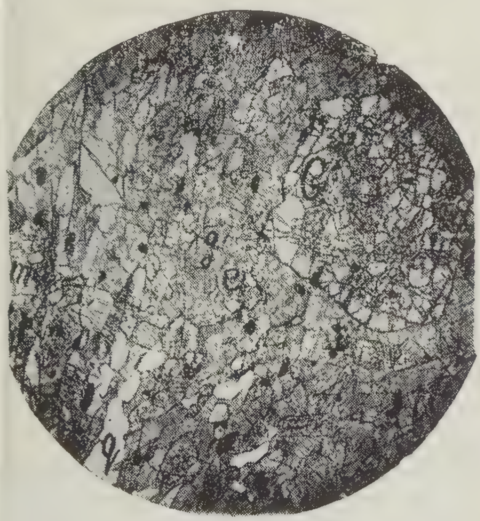

FIGURE 2. Epidote-glaucophane eclogite: G-garnet; ep-epidote; om-omphacite, q-quartz; rutile (black without analyzer); d=6 mm

the marginal parts of the bodies.

In Table 1 chemical analyses are given for rutile-bearing eclogites and garnet-glaucophane rocks from the western part of the deposit. For comparison, a chemical analysis of garnet-muscovite-quartz schist is also provided (anal. [illegible]). The latter rock is a metamorphosed eclogite.

Thus, the chemical compositions of eclogite and garnet-glaucophane schists are very close. Across the whole ore body the Ti/Fe ratio is very consistent and varies from 0. 21 to 0. 26.

The high ratio of these two elements is generally typical of old metamorphic rocks of the Urals.

Evidently, the eclogites of Shubino deposit are products of the metamorphism of gabbroic igneous rocks, as evidenced by the following:

1. Close chemical composition of eclogites and gabbroic rocks.

2. Regular distribution of components in the ore bodies. In the case the distribution of rutile is traced to origin from an igneous rock by metamorphism, and isomorphism was discontinuous between Mg, Fe and Ti in pyrogenetic silicates [7, 3].

3. Uniformity of the rock texture, similar to a massive texture, and sharp contacts of the ore bodies with enclosing rocks.

Eclogites, to a certain degree, underwent

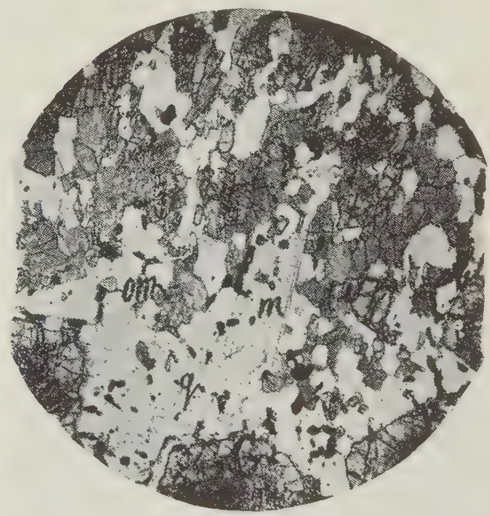

FIGURE 3. Quartz-muscovite-glaucophane eclogite; G-garnet; q-quartz; om-omphacite; g-glaucophane; m-muscovite; rutile-black, without analyzer; d=6mm

retrogressive metamorphism. This fact resulted in metamorphism of eclogites to garnet-muscovite-quartz schists, to amphibolites and partially to greenstones. The garnet-muscovite-quartz schists, which are metamorphic products of eclogites are light-gray rocks with a coarse schistose structure and contain red or pink porphyroblasts of garnet.

The amount and size of garnet and rutile crystals in these schists are the same as in the eclogites. The amount of quartz in schists reaches 40-50 percent and of muscovite 20-30 percent (fig. 4).

TABLE 1. Chemical analyses of rutile-bearing eclogites

Oxides	Analyses				
	1	2	3	4	5
SiO_2	46.93	46.35	49.44	47.80	55.56
TiO_2	5.35	3.32	4.85	3.81	2.50
Al_2O_3	12.65	13.77	15.48	15.61	19.00
Fe_2O_3	6.04	5.74	5.55	4.93	1.64
FeO	8.54	8.97	8.76	8.96	8.60
MnO	0.28	0.09	0.21	0.19	0.16
MgO	5.91	7.22	4.92	5.62	3.73
CaO	9.10	9.99	6.04	6.58	3.45
Na_2O	2.72	2.97	2.48	3.10	0.62
K_2O	0.46	0.18	0.42	0.44	3.76
H_2O	0.18	-	0.24	0.76	-
P_2O_5	0.45	0.25	0.19	1.03	-
V_2O_5	0.10	0.06	0.10	0.07	-
Loss by ignition	0.72	1.32	0.68	0.96	1.80

a	c	b	s	l'	m'	c'	n	t	ϕ	Q	ac
6.7	5.2	29.6	58.5	46.2	33.8	20.0	90.7	8.0	17.6	-1.6	1.3
6.8	5.8	32.0	55.4	42.2	38.2	19.6	96.0	5.0	15.3	-8.6	1.17
6.2	7.8	22.6	63.4	61.6	38.4	0.0	90.8	6.8	21.9	+6.6	0.8
7.7	7.1	24.8	60.4	54.1	40.1	5.8	92.5	5.7	17.3	-1.7	1.3

Zavaritsky's parameters are used.

Analyses: 1-glaucophane-eclogite; 2-epidote-glaucophane eclogite; 3-quartz-muscovite-glaucophane eclogite; 4-garnet-glaucophane schist; 5-garnet-muscovite-quartz schists, formed after eclogite. Analyses by Yu. A. Ravkovskaya and N. N. Dulova (Mining Institute of Sverdlovsk).

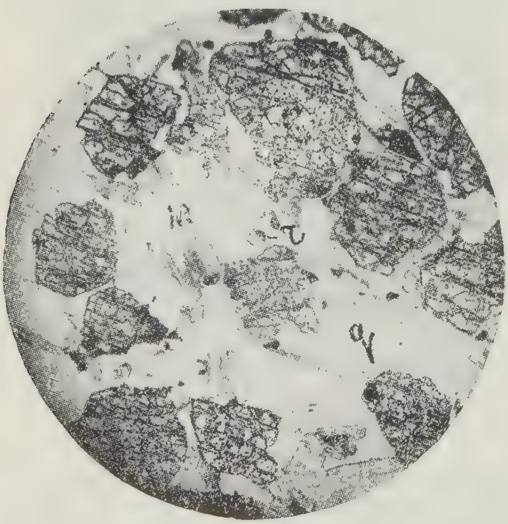

FIGURE 4. Garnet-muscovite-quartz schists; G-garnet; q-quartz; m-muscovite; r-rutile (without analyzer); d=6 mm

The chemical analysis of this rock is given in Table 1. The groundmass of the schists commonly contains relict grains of green omphacite and dark-blue glaucophane. Such grains in schists sometimes contain agglomerates which are relicts of the major texture of eclogite.

Transition of eclogites into garnet-muscovite-quartz schists is more pronounced in near-contact zones of the ore bodies. The process of alteration of eclogites starts with the granulation of quartz lenses around porphyroblasts of garnet oriented concordantly with the schistosity (see fig. 6.) In the next stage, quartz and muscovite are developed throughout the main mass of the rock, replacing glaucophane and ompacite. One can often observe isolated relict grains of glaucophane and omphacite in the aggregate of muscovite and quartz, which show simultaneous extinction. The alteration of eclogite starts in isolated spots, usually up to several decimeters in cross section. Near the margins of ore bodies such metamorphic spots are concentrated in bands, and zones of garnet-muscovite schists up to 5-10 cm thick are formed near the contacts of the enclosing rocks. An example of partly metamorphosed eclogite is quartz-muscovite-glaucophane eclogite (fig. 3).

Amphibolitization of the eclogites is more pronounced in places where ore bodies wedge out. Small bodies of eclogites 10-30 m thick are almost entirely amphibolitized. Where this kind of amphibolitization progresses, only garnet is preserved from the original rock. Groundmass minerals are replaced by amphiboles of the actinolite type and rutile is almost entirely transformed to fine-grained sphene (fig. 5). Such amphibolitized eclogite is bluish-

FIGURE 5. Amphibolitized eclogite; G-garnet; A-amphibolitized groundmass (without analyzer); d=6 mm

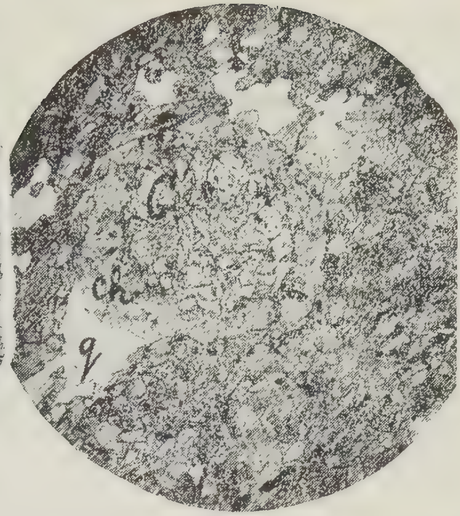

FIGURE 6. Epidote-glaucophane eclogite, partly chloritized; G-garnet; ch-chlorite, q-quartz (without analyzer)

gray or dark bluish-gray and very tough.

The rocks of the deposit have undergone greenstone metamorphism on an insignificant scale. In peripheral parts of ore bodies such minerals as garnet, pyroxene and amphibole are replaced more or less by epidote and green chlorite (fig. 6). In such places, up to 1 percent of the plagioclase is close to albite in composition.

Many facts definitely indicate that metamorphic transformation of eclogites into garnet-muscovite-quartz schists took place earlier than amphibolitization and greenstone alteration. Primarily this is indicated by such features as unchanged rutile and garnet and also relicts of eclogite. Processes of amphibolitization and greenstone metamorphism of eclogites are quite common [10, 14, 15, 16, 19], but the changes of eclogites to garnet-muscovite-quartz schists have not been described in the literature. In the area of this study the process of eclogite alteration is a usual phenomenon.

Two sets of quartz veins of different age cut eclogites of the Shubino deposit. One set of veins is concordant with the strike (about 380° NW)[2] and consists of fine-grained transparent quartz. The thickness of these veins is about 20 cm, and they extend 20-30 m along the strike. Contacts of the veins with the host rocks are not sharp. The eclogites near the veins are enriched in quartz and muscovite. The veins contain many eclogite fragments. The inclusions have the same orientation as the host rocks, and their minerals show no visible changes.

Muscovite is almost always present in veins in amounts of 5 to 10 percent. Small, short prismatic crystals of brown rutile are also present in the veins. In the broad parts of the veins one can see blocks of semi-transparent quartz surrounded by fine grained quartz. Granular quartz penetrates into these blocks along fractures. Near these blocks, granular quartz surrounds separated parts of blocks which have the same orientation as the blocks. This relationship shows that quartz in this case is granular and originated from transparent quartz during deformation of the veins [2].

The second set of quartz veins is younger than the first and cuts eclogites and older veins. Usually these veins are not more than 1-3 cm thick, but in the main ore body some are more than 1 meter thick. The strike of these veins is about 65° NE and the dip is almost vertical. The contacts of veins with the host rocks are sharp and linear. Eclogites near the veins are slightly amphibolitized and rutile is replaced by sphene. The veins consist of milky-white quartz and variable amounts of epidote and sphene which are concentrated in salbands. Albite, pyrite and acicular bluish-gray amphiboles are rarely present in the veins. On the basis of morphologic and paragenetic characteristics the younger veins could be considered as Alpine type.

Apparently these two sets of veins of different ages are related genetically to retrogressive metamorphism of the eclogites. Veins of the first type are genetically related to the

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[2] Probably 330° is meant. This would be the mean of the strikes given in paragraph 3 of this work.--E.I.

metamorphism of eclogites, during which garnet-muscovite-quartz schists are formed. Veins of the second type are related to the amphibolitization and greenstone metamorphism of eclogites.

Metamorphic rocks of the M series, including eclogite and glaucophane rocks, extend to the Bashkirian Urals, far north of Shubino village. These rocks are observed in good sections in the valley of the Sakmara river in the Khaybulinsky district of Bashkir A.S.S.R. The glaucophane and garnet-glaucophane rocks with pyroxene occur farther to the north of this area, in the region of Temyasovskoe village and were described in 1928 by F. N. Shakhov [19]. In the M series of the Bashkirian Urals similar rocks were studied by D. G. Ozhiganov [9] but these two authors did not single out the eclogites.

In Soviet geological literature we found no record of eclogites similar to the rutile-bearing eclogites of Shubino. The eclogites from the Kokchetav district in Kazakhstan [16], from Kiv and Kazotski bay on the White Sea [11], the eclogites from kimberlite pipes of Siberia [1] differ considerably in mineralogically chemically, and there is little in common geologically.

There is a considerable similarity between the Shubino region and the Coastal Range in California, where glaucophane schists and eclogites are surrounded by metamorphosed sedimentary rocks [21, 22]. Ultrabasic intrusions play an important role in similar regions of California, and some geologists relate the origin of glaucophane rocks to ultrabasic intrusions.

The chemical and mineralogical composition of rutile-bearing eclogites from Shubino village has considerable similarity to low-silica eclogites of Europe and America [10, 20]. It is characteristic that eclogites and glaucophane schists with a lower silica content contain a higher amount of titanium, a conclusion evident from a comparison with published analyses [10, 20]. The rutile-bearing eclogites from Shubino village, containing a high percent of titanium, evidently do not have analogs in the geological literature, especially if we keep in mind that all titanium in the eclogites is in rutile.

DESCRIPTION OF PRINCIPAL MINERALS OF THE DEPOSIT

The following minerals are found in the rutile-bearing eclogites from the Shubino deposit (in order of decreasing abundance): glaucophane, garnet, omphacite, epidote, muscovite, quartz, rutile, sphene, chlorite, apatite ilmenite, carbonates, pyrite, pyrrhotite, chalcopyrite. plagioclase, and molybdenite. The following minerals are found in small amounts in the weathered zone: limonite, psilomelane, nontronite, magnesite, malachite and azurite. Description of these minerals follows in this order. Crystallochemical formulas are calculated for all minerals according to V. S. Sobolev's method [12].

In most cases glaucophane forms not less than 40-50 percent of the groundmass of the rock. The size of glaucophane grains is on the order of 1 mm parallel to the long axis. The grains are prismatic. Garnets with (110) and (100) forms are sometimes developed. The specific gravity determined by means of pycnometer is 3. 24. Color of the glaucophane is dark-blue to bluish-black. Under the microscope it is strongly pleochroic: Z -- sky-blue or blue, Y -- grayish-violet, X -- slightly yellowish or almost colorless. Biaxial negative, positive elongation, angles with Z are about 6° - 9°. Low dispersion, $\rho > \nu$. Indices of refraction, determinated by the immersion method, are:

$$\gamma \text{ -- } 1.662, \quad \alpha \text{ -- } 1.641, \quad \gamma - \alpha = 0.021.$$

The chemical analysis of glaucophane from the eclogite is given in Table 2. This analysis was carried out in the laboratory of the Geological Survey of the Urals.

Due to alteration the glaucophane commonly is changed to a greenish-blue amphibole with 2V up to 24°, which is close to so-called "anomalous glaucophane" [4]. It also changes to an amphibole close to actinolite.

Garnet constitutes not less than 30 percent of the entire rock. Crystals of garnet vary from 3 to 5 mm in diameter. In most cases the crystals of garnet are rhombic dodecahedra. The central parts of these crystals usually include portions of the groundmass (fig. 1). The specific gravity of garnet is 2. 03 (pycnometer determination)[3]. It is pinkish to brown-red. The index of refraction is 1. 82 (determined on fusions).

Chemical analysis of garnet is by Yu. A. Ravkovskaya and N. N. Dulova (table 3).

Garnet consists of (in molecular percent): 57. 8 -- almandite; 18. 1 -- grossularite; 13. 7 -- pyrope; 8. 8 -- andradite; 1. 7 -- spessartite.

Titanium is not taken into consideration because it is related to minute visible impregnations of rutile.

During metamorphism of the eclogites,

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[3] Garnet of this composition should be closer to 4.03-E.I.

TABLE 2. Chemical analysis of glaucophane from eclogite

Oxides	Weight percent	Atomic amount of oxygen	Molecular amount	Number of oxygen atoms calculated for 24	Atomic amount of cations	Number of cation atoms
SiO_2	54.90	914	1,828	15.59	914	7.80
TiO_2	0.78	10	20	0.17	10	0.08
Al_2O_3	11.20	110	330	2.82	220	1.88
Fe_2O_3	2.96	18	54	0.46	36	0.31
FeO	12.10	168	168	1.43	168	1.43
MnO	0.01	-	-	-	-	-
MgO	7.12	176	176	1.50	176	1.50
CaO	0.96	17	17	0.14	17	0.15
Na_2O	6.78	110	110	0.94	220	1.88
K_2O	0.05	-	-	-	-	-
H_2O	2.00	111	111	1.00	222	2.00
Cr_2O_3	0.006	-	-	-	-	-
V_2O_5	0.06	-	-	-	-	-
Total	98.93					

Annotation: Formula $(Na_{1.88}\ Ca_{0.15})_{2.03}\ (Mg_{1.50}\ Fe^{\cdot\cdot}_{1.43}\ Fe^{\cdot\cdot\cdot}_{0.31}\ Al_{1.68}\ Ti_{0.08})$ $(OH)_2[Al_{0.20}\ Si_{7.80}\ O_{22}]$.

TABLE 3. Chemical analysis of garnet from eclogite

Oxides	Weight percent	Weight percent without Ti	Molecular amount	Atomic amounts of oxygen	Number of oxygen atoms calculated for 12	Atomic amount of cations	Number of cation atoms
SiO_2	38.16	38.29	638	1,276	5.97	638	2.98
TiO_2	1.13	-	-	-	-	-	-
Al_2O_3	22.30	22.38	220	660	3.09	440	2.06
F_2O_3	2.75	2.76	17	51	0.24	34	0.16
FeO	23.90	23.97	334	334	1.56	334	1.56
MnO	0.69	0.70	10	10	0.05	10	0.05
MgO	3.21	3.23	79	79	0.37	79	0.37
CaO	8.64	8.67	155	155	0.72	155	0.72
Cr_2O_3	Traces						
V_2O_5	Traces						
Total	100.78	100.00		2,565	12.00		

Annotation: 1) Common divisor: 2,565 : 12 = 213.75. 2) Formula: $(Fe^{\cdot\cdot}_{1.58}\ Ca_{0.72}\ Mg_{0.38}$ $Mn_{0.05})_{2.70}\ (Al_{2.06}\ Fe^{\cdot\cdot\cdot}_{0.16})_{2.22}\ [Si_{2.98}\ O_{12}]$.

part of the garnet changes into a chlorite close to pennine. The chemical composition of garnet from Shubino eclogites is very similar to garnets from eclogites of California and to garnet from some eclogites from Vanelvasalen, Norway [20].

Omphacite is commonly present in the rock in amounts of about 30 percent of the groundmass; rarely, 60-70 percent. In such cases the parts rich in omphacite constitute only small bands.

Grains of omphacite are flat prisms, flattened along (100) and reach 0.5-1.0 mm in size. The faces (100), (110) and (010) are rarely present on grains. The specific gravity of omphacite is 3.36 (pycnometer determination). The mineral is dark-green and has strong vitreous luster. Under the microscope it is transparent, slightly pleochroic: Z -- pale-green, Y -- slightly greenish-brown, X -- greenish-pale. The mineral is positive, +2V is about 70°, has negative elongation and the angle with Z is about 70°. There is considerable dispersion of optical axes ($\rho > \nu$). Indices of refraction are: γ -- 1.712, α -- 1.690, $\gamma - \alpha = 0.022$. The mineral was chemically analyzed in the laboratory of the Geological Survey of the Urals (table 4).

Thus, the pyroxene from rutile-bearing

TABLE 4. Chemical analysis of omphacite from eclogite

Oxides	Weight percent	Molecular amount	Atomic amount of oxygen	Number of oxygen atoms calculated for 6	Atomic amount of cations	Number of cation atoms
SiO_2	53.48	891	1,782	3.85	891	1.92
TiO_2	0.59	8	16	0.03	8	0.02
Al_2O_3	11.37	112	336	0.73	224	0.49
Fe_2O_3	6.51	41	123	0.26	82	0.17
FeO	1.42	19	19	0.04	19	0.04
MnO	0.01	-	-	-	-	-
MgO	7.33	181	181	0.40	181	0.40
CaO	12.28	219	219	0.46	219	0.46
V_2O_5	0.10	-	-	-	-	-
Cr_2O_3	0.017	-	-	-	-	-
Na_2O	6.30	102	102	0.23	204	0.46
K_2O	0.02	-	-	-	-	-
Losses due to ignition	0.43	-	-	-	-	-
Total	99.86		2,778	6.00		

Annotation: 1) Common divisor: 2778 : 6 = 463. 2) Formula: $Na_{0.46}(Mg_{0.40}Fe^{\cdot\cdot}_{0.04}Ca_{0.45}Ti_{0.02})_{0.91}F^{\cdot\cdot\cdot}_{0.17}Al_{0.41}[Al_{0.08}Si_{1.92}O_6]$.

eclogite of Shubino is a typical eclogitic omphacite, very close in chemical composition to omphacites from eclogites of Europe (France, Norway) and California [10, 20, 21].

Epidote in epidote-glaucophane eclogites makes up to 20 percent of the groundmass. Spindle-shaped crystals of epidote are up to 1 mm in size. The interior of epidote grains contains abundant inclusions of the eclogite groundmass. Under the microscope epidote is almost colorless, biaxial negative, angle with Z is about 74°. Indices of refraction are: γ -- 1.743, α -- 1.727, $\gamma - \alpha$ = 0.016. According to optical properties this epidote is a variety with low iron content.

Muscovite forms flakes in the rock 2-3 mm in diameter. These flakes are yellowish-white with indices of refraction $\gamma - \beta$[4] = 1.590. It is pseudo-uniaxial negative. Its birefringence across the cleavage is very high. Muscovite from drilling cores of 50-100 m depth shows under the microscope a noticeable birefringence. Chemical analysis of muscovite from the rutile-bearing eclogite is given in Table 5 (analysis by Yu. A. Ravkovskaya and N. N. Dulova).

Titanium is not taken into consideration since most of it is related to visible rutile inclusions.

Quartz in the rock occurs in small transparent grains and aggregates. Quartz grains are concentrated in veinlets or in lenses around garnet crystals. Sometimes quartz grains show a weak wavy extinction.

Sphene in the rutile-bearing eclogites occurs as product of metamorphism of rutile grains, and it surrounds these grains as a fine grained halo. In quartz-epidote veins of the Alpine type, greenish-yellow crystals of sphene are present sometimes and have the shape of lenses, 1-2 cm in diameter. The indices of refraction of such crystals are γ -- 2.04, α -- 1.95, $\gamma - \alpha$ = 0.09.

The chemical analysis of sphene from veins of Alpine type in eclogites is given in Table 6. The analysis was carried out by N. I. Zabavnikova at the Institute of Ore Deposits, Petrography, Mineralogy and Geochemistry of the Academy of Sciences of the U. S. S. R.

Rutile. In samples of rutile-bearing eclogites the amount of TiO_2 was determined by means of chemical analysis. The amount of rutile was determined under the microscope. The mineralogical analysis was carried out according to the method described by A. A. Glagolev [6]. This method, based on the use of powder for calculation, was slightly modified by scientists of this institution. The distribution of rutile in the rock is quite regular in a horizontal as well as vertical direction. Under the microscope six thin sections from various parts of the ore body were studied and 1,200 grains of rutile from these thin sections were measured. This study has revealed that rutile in this rock consists mainly (about 60 percent) of grains 0.1 mm or greater in size. (fig. 7).

The proportion of grains of rutile in the

[4] A line appears to have been omitted from the Russian text here. The value given is probably $\gamma = 1.590$, those for β and $\gamma - \beta$ omitted.-E.I.

TABLE 5. Chemical analysis of muscovite from eclogite

Oxides	Weight percent	Weight percent without Ti	Molecular amount	Atomic amounts of oxygen	Number of oxygen atoms calculated for 12	Atomic amount of cations	Number of cation atoms
SiO_2	48.16	48.47	808	1,616	6.57	808	3.28
TiO_2	0.82	-	-	-	-	-	-
Al_2O_3	28.43	28.60	281	843	3.46	562	2.30
Fe_2O_3	2.93	2.95	18	54	0.22	36	0.14
FeO	1.31	1.32	18	18	0.07	18	0.07
MnO	0.04	0.04	6	6	0.02	6	0.02
MgO	2.53	2.55	64	64	0.25	64	0.25
CaO	0.16	0.16	4	4	0.02	4	0.02
Na_2O	0.50	0.50	8	8	0.03	16	0.06
K_2O	9.10	9.15	97	97	0.38	194	0.76
Cr_2O_3	0.05	0.05					
V_2O_5	0.16	0.16					
H_2O	5.98	6.06	339	(339)246	1.00	492	2.00
Total	100.17	100.00		3,049			
				-93 2,956			

Annotation: 1) Common divisor: 2956 : 12 = 246

$$X = \frac{2mC-kA}{2m-k} = \frac{2.12.339-2.3049}{2.12-2} = 93$$

x = 93 : 246 = 0.38

2) Formula: $K_{0.76}\,Na_{0.06}\,Ca_{0.02}\,Mg_{0.25}\,Fe^{\cdot\cdot}_{0.07}\,Fe^{\cdot\cdot\cdot}_{0.14}\,Al_{1.58}\,(OH)_2\,[Al_{0.72}\,Si_{3.28}\,O_{10}] \times 0.38H_2O$.

TABLE 6. Chemical analysis of sphene from veins of Alpine type occurring in eclogite

Oxides	Weight percent
SiO_2	30.98
TiO_2	38.98
Al_2O_3	0.93
Fe_2O_3 / FeO	0.45
MnO	0.02
MgO	Absent
CaO	28.08
SrO	Not detected
TR_2O_3	Not detected
Na_2O / K_2O	0.14
F	0.18
H_2O+	0.22
H_2O-	0.41
Total	100.41
-F=O	0.08
Total	100.33
Specific gravity	3.512

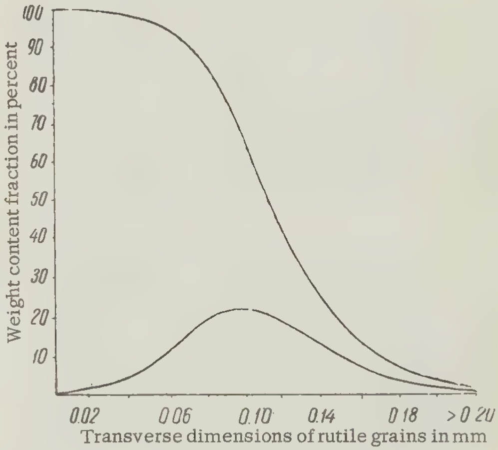

FIGURE 7. Diagram of fractional composition of rutile in eclogites

groundmass of the rock is five times greater than in the porphyroblasts of garnet, where rutile inclusions are very small and of irregular radiating shape.

Most of the crystals of rutile are prismatic and the ratio of width to length is about 1 : 2. Angles and faces of the crystals are very regular. The more euhedral crystals possess the faces (110), (100), and (111). Faces of first and second order prisms are almost equally developed. In the upper parts of the bodies to the depth of 20-40 m, rutile is transparent and is dark-red. With depth this color becomes darker and at depths of 50-100 m the rutile is black with a violet tinge. Evidently the weathering processes change the original color of the

mineral to red. Specific gravity of red rutile is 4.23 (pycnometer determination), the mean index of refraction is 2.6 (determined on fusions).

The chemical analysis of red rutile from the rutile-bearing eclogite is given in Table 7.

TABLE 7. Chemical analysis of rutile from eclogite

Oxides	Weight percent
SiO_2	0.36
TiO_2	94.18
Al_2O_3 Fe_2O_3	5.00
FeO	Absent
MnO	Traces
MgO	0.26
CaO	0.03
Cr_2O_3	0.014
V_2O_5	0.32
Na_2O K_2O	0.12
Losses due to ignition	0.12
Total	100.40

The mineral was analyzed in the laboratory of the Geological Survey of the Urals.

In the earlier quartz veins, which consist of granular quartz, rutile occurs in inclusions of eclogites, as well as in quartz. Rutile from the inclusions does not differ at all from rutile of the eclogites; it is not a vein mineral. In quartz crystals at the salbands of veins, short prismatic brown crystals of rutile, 1-2 cm in length, occur. These crystals frequently are doubly terminated the following faces are developed: (111), (100), (110). All prism faces are well developed, are smooth, and lack striations.

In the vicinity of the deposit, in pebbles of milky-white quartz, frequently occur acicular and long prismatic crystals of brown rutile without terminal faces and with rough vertical striation. These crystals are up to 5-10 cm long and are 0.5-1.0 cm thick. Apparently these crystals originate from veins of the Alpine type, although they were not found in the veins.

CONCLUSIONS

1. The area of distribution of glaucophane and eclogite rocks in the vicinity of Shubino village in the Southern Urals constitutes the southern end of the zone of crystalline schists of the M series. This series contains the glaucophane and eclogite rocks and it continues farther north into the Bashkirian part of Aral-Tau Range.

2. In the vicinity of Shubino village glaucophane and eclogite rocks are especially well developed and are represented by many varieties. A characteristic feature of these rocks is that they contain bodies of rutile-bearing eclogites which attain considerable size.

3. On the basis of geological, structural, mineralogical and chemical studies of rutile-bearing eclogites, it is permissible to assume that these rocks were formed by the metamorphism of basic igneous rocks with a high titanium content.

4. Along with manifestations of retrogressive metamorphism of eclogites (amphibolitization, greenstone metamorphism), eclogites have undergone transformations into garnet-muscovite-quartz schists.

5. Results of preliminary technological testing of the rutile-bearing eclogites justify the assumption that these rocks can be of economic interest as ores for production of rutile and garnet concentrates [3, 13].

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CHARACTERISTIC FEATURES OF ORE DEPOSITS FOUND IN CONTACT-METAMORPHIC AUREOLES IN JAPAN[1]

by

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• *translated by Kinkiti Musya* •

ABSTRACT

In contact metamorphic aureoles developed mostly between Paleozoic and Mesozoic rocks and later intrusive masses are found various kind of ore deposits of pneumatolytic and hydrothermal origin. In calcareous environments many replacement deposits of Ca-Fe-skarn type occur commonly, while pneumatolytic to hydrothermal veins are found along fissures in noncalcareous sediments.

After explaining general features of the skarns found in contact-aureoles, modes of occurrence of metalliferous deposits of contact zones are described in detail.

Thermal metamorphism of manganese deposits associated with siliceous sediments are also explained. --Author.

CONTENTS

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[1] Translated from the Japanese:in Jubilee Publication in the Commemoration of Professor Jun Suzuki, M.J.A. Sixtieth Birthday (1956), p. 169-192, 1958.

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INTRODUCTION

In general, igneous rock bodies are surrounded by contact metamorphic aureoles resulting from the effect of heat of intruded magma or addition of substances. The width of such aureoles differs according to the bulk and lithologic character of igneous rock bodies, but generally it is several hundred meters to several kilometers in maximum.

In contact metamorphic aureoles are commonly many metalliferous deposits of the same origin as the magma from which the igneous rocks originated.

In places, mineral composition has been complicated by thermal metamorphism or contact metasomatism of pre-existing ore deposits.

Of these ore deposits, there are many accompanied by skarns in a contact zone containing limestone or dolomite. Skarns are striking assemblages of minerals found in the contact metamorphic aureoles, and ore deposits associated with skarns are called contact deposits, contact metasomatic deposits, or sometimes pyrometasomatic deposits.

However, genetic study of many ore deposits reveals that the characters of rocks in the contact zone determine whether high temperature type ore veins not accompanied by skarns are developed or skarn type pyrometasomatic deposits. That is, even if almost similar mineralized liquid is released from the magma, in the presence of calcareous rocks, skarns are produced but in their absence common quartz veins are formed.

Skarn is a Swedish term referring to a mineral assemblage consisting of fibrous or columnar diopside and tremolite, accompanied by garnet and epidote, which occur as gangue minerals in iron ore deposits in central Sweden. Originally it was a local mining term meaning a candlewick. Later it was used by geologists for a complicated assemblage of silicate minerals of Ca, Mg, Fe, and Mn. Consequently, the term is sometimes used with no connotation of origin.

However, on the basis of studies recently made by petrologists and mineralogists, it is clear that skarns may differ in origin.

That is, some ore deposits accompanied by skarns in the contact zone existed previous to the intrusion of igneous rocks and so were metamorphosed by them, and in others skarns produced by previous metamorphism were again altered by intrusion of igneous rocks resulting in extremely complicated deposits.

The writer who began study of ore deposits in contact metamorphic aureoles in the Suan gold mine, Korea, in 1931, has continued his study of skarns and the mode of occurrence and paragenesis of minerals associated with them. In the field and while reading the literature, he has often considered the genesis of the so-called contact deposits.

In this paper, I will summarize the characteristics of many ore deposits in contact metamorphic aureoles in Japan.

When I was studying the contact ore deposits of Suan at Hokkaido University, Jun Suzuki published the result of his research on the Ofuku ore deposits carried out from 1922 to 1932. During my study of contact zones Professor Suzuki afforded valuable instruction and encouragement and excellent research facilities were available. I take this opportunity to thank Professor Suzuki for his extended guidance and encouragement.

HISTORICAL SKETCH OF THE STUDY OF ORE DEPOSITS IN CONTACT ZONES IN JAPAN

From the early Meiji period [Tr. : 1868-1912] to the Taisho period [Tr. : 1912-1926] metalliferous deposits in Japan began to be developed. Skarn type contact deposits of copper, iron sulphide, etc. attracted many enterpriser's attention at first. In the oxidized zones of these deposits various secondary minerals of copper aggregated and had formed secondary enrichment zones which were developed first. The copper mines of Yakuki, Mochikura, Sasagatani, Naganobori, Zō-meki, etc. were well-known in the Taisho period, but later the enrichment parts near the surface were exhausted and they were abandoned.

In the period when contact deposits were actively developed, Nobuyo Fukuchi published an interesting paper on the zonal distribution of skarn minerals in the contact deposit zone. It was the first paper on this phenomenon, and attracted attention of investigators of ore deposits throughout the world. For example, a full-page quotation from this paper appears in Lehre von den Erzlagerstätten [Textbook of Science of Ore Deposits] by Beck (1909).

Later, Bunjiro Koto published a petrographic paper describing the country rock and skarns of the Holgol ore deposits in the Suan district, Korea.

In the period 1910-1920, contact deposits were much studied throughout the world. In Europe an epoch-making study on Christiania was published by V. M. Goldschmidt. With the development of the contact deposits in America and Mexico many papers on the origin of contact deposits were published in Economic Geology.

The origin of garnet skarn zone associated with contact deposits was the principal problem in this period. Takeo Kato made important observations in Kyushu on the sequence of formation of skarn minerals and published a preeminent opinion on the changes of mineral solution during mineralization.

Ore deposits in the Tohoku district, namely, Hitachi and Yakuki, were studied at Tohoku University first by Masao Oyu, later by Manjiro Watanabe and his colleague. Watanabe's view on those ore deposits was summarized in "Contact Ore Deposits" in the Iwanami Koza (Iwanami Science Series).

Takeo Kato was followed by Jun Suzuki, who studied contact metasomatism in the Ofuku deposits of the Chugoku district and in 1932 published his view on the origin of contact metasomatic deposits together with detailed descriptions.

After that, many contact deposits in Japan were abandoned as ores in the surface were exhausted. Mining was continued only in the zinc deposits of Kamaishi, Kamioka, and Nakatatsu, which were studied in detail.

Since World War II the study of mining geology has resumed and the prospecting and development of irregular-shaped ore bodies in deposits of contact zones have become a subject for investigation. A particular object of study has been the problem of structural mechanism in situ. Moreover, contact deposits were reexamined for the possible utilization of paragenic minerals. Thus skarn and sulphide minerals in contact zones have been studied in more detail than before World War II, and genetic classification of skarns also has become possible. Recent progress has been summarized by Watanabe and Miyazawa.

Development of copper ores associated with iron ores and utilization of pyrrhotite in Kamaishi, the reopening of mines at Akagane, Yakuki, and elsewhere, and good results from deep test borings have restored interest in contact deposits.

Consequently the study of various skarn minerals and metalliferous minerals has been encouraged again. Further, many foreign petrologists are studying skarns, and interesting papers are published from time to time.

I turned my attention from the contact zones in Korea to those in Japan, and found that there is a striking difference in paragenesis of minerals in the skarn zones between areas where limestone is the original rock and areas where dolomite is the original rock.

Moreover, there are many manganese deposits in the Paleozoic formations of Japan. When these deposits are intruded by granite, the deposits are subjected to contact metamorphism, and paragenesis of minerals is considerably changed. Sometimes deposits of cupriferous iron sulphide are changed by contact metamorphism. Changes of older ore deposits due to the effect of younger igneous rocks are very interesting from the viewpoints of mineralogy and science of ore deposits.

GENETIC CLASSIFICATION OF METALLIFEROUS DEPOSITS IN CONTACT ZONES

High or moderate temperature ore deposits are distributed near the margin of plutonic rock masses. In the types of these deposits there is a striking difference between areas where the country rock is carbonate and areas where the country rock is not carbonate.

Contact Deposits with Limestone or Magnesian Limestone

In this case most of the deposits are of the contact metasomatic type mainly consisting of skarn minerals containing Ca and Mg gangue minerals. These deposits mostly occur along the contact plane of an igneous rock mass, but sometimes these deposits are found within the igneous rock mass apart from the contact plane, or in rock several hundred meters or 2 to 3 km from the igneous rock mass. These deposits have been considered deposits of the same type by reason of occurrence of skarn minerals in them and have long been called contact deposits. However, ores attributable to the same solutions which formed the host rock have been complicated in their contents. Formerly there were many scientists who considered that deposits of this type were formed by mineralizers directly released at the contact plane of the intruding plutonic rock. However, later studies revealed that many deposits of this type were formed after the margin of the intrusive had solidified. That is, mineralizing fluid of high temperature released from molten magma still within the igneous rock mass migrates from within along a weak line or fissure to the zone of contact. On contact with such rock as limestone or magnesian limestone, a reaction takes place and the ores associated with various skarns are produced. Lindgren called these pyrometasomatic deposits instead of contact deposits. However, they are found mostly in contact zones, so I shall call them contact metasomatic deposits. Genesis of these deposits is complex indeed. Based on the depth where deposits are formed, the nature of mineralizing fluid, etc., these deposits are classified as follows:

Contact Pneumatolytic Metasomatic Deposits

This type is mostly found in the vein deposits produced from high temperature mineralizers

and skarns yielding tungsten, tin, iron, and fluorspar. (Examples: Part of Obira, Kiwada, Kuka, Mihara, and Kamaishi).

Contact Pneumatolytic-hydrothermal Migration Deposits

Among the so-called contact deposits of copper, lead, zinc, etc., there are many in which ore minerals, formed later than the skarns, have been produced together with hydrothermal vein fillings. The final stage of formation of these deposits is characteristic of hydrothermal deposits, and metalliferous ores were produced mainly in the hydrothermal stage. (Examples: Copper deposits in Kamaishi, Kamioka, and Chichibu.)

Pneumatolytic-hydrothermal Ore Veins Associated with Skarns

Some of fissure-filling ore veins in areas where limestone and slate alternate are accompanied by various high-temperature skarn minerals. In this case mineralizing fluid released from the magma came in contact with limestone or similar rock, and was partly assimilated, resulting in skarn minerals. In limestone, deposits of this type sometimes grade into metasomatic deposits. (Examples: Copper deposits in Yoshioka and Kawayama.)

Deposits Accompanied by Skarns Produced by Repeated Mineralization

In the case where hydrothermal mineralization recurs repeatedly in an area of deposits of the first two types above minerals of complicated paragenesis are produced. In this case the pre-existent skarn deposits undergo alteration by hydrothermal action. In a region like Japan where recurring igneous activity has prevailed there are many examples of such complicated deposits. (Examples: Akatani and Iitoyo.)

Deposits in the Contact Zone of Quartzite and Slate (zone which lacks limestone and magnesian limestone)

High-temperature mineralizing fluid released from magma enters into fissures of a rock which has changed into hornfels and produces pneumatolytic or hydrothermal deposits. In porous rocks the fluid forms impregnation deposits.

Pneumatolytic Ore Veins

Vein minerals are mainly quartz and ores of tin, tungsten, molybdenum, etc. accompanied by tourmaline, mica, and feldspar. The country rock has been subject to metamorphism peculiar to pneumatolytic deposits such as greisenization, silicification, and fluoritization. (Examples: Takatori, Kaneuchi, and Yakuoji.)

Pneumatolytic-hydrothermal Migration Deposits

These are deposits of vein type produced by mineralization which continued from the pneumatolytic period of high temperature to the hydrothermal period of moderate temperature. Chlorite, sericite, and carbonate minerals appear as vein minerals of the final period; hydrothermal metamorphism of the country rock is also noticed. Polymetallic ores of tin, copper, lead, and zinc are abundant. (Examples: Copper-tin ore veins in Obira and gold-tungsten ore veins in the southern part of the Kitakami Mountainland.)

Pre-existing Ore Deposits Subjected to Contact Metamorphism

There is a situation, though relatively rare, in which pre-existing ore deposits undergo thermal metamorphism by the intrusion of igneous rock resulting in peculiar mineral constituents. Coal seams or carbonaceous strata change into graphite deposits by such thermal metamorphism.

Siderite and hematite deposits frequently become magnetite deposits accompanied by skarn minerals, and bedded manganese deposits containing manganese carbonates change into deposits of manganese silicate accompanied by various manganese skarn minerals.

Sometimes deposits containing sulphate minerals are also subjected to thermal metamorphism, and cupriferous pyrite deposits change into cupriferous pyrrhotite accompanied by cubanite, pyrrhotite, and magnetite.

Good examples are found in the magnetite deposits of the reaction-skarn type in central Sweden, the pyrrhotite deposits in Makimine and Yanahara, and the manganese silicate deposits accompanied by manganese skarns in the Chichibu Paleozoic system at Noda-Tamagawa and Kaso. In these cases metasomatism takes place frequently as substances are newly supplied from magma. Consequently the mineral composition of altered metamorphosed deposits are mostly very complicated.

GENETIC CLASSIFICATION OF SKARN, PARAGENIC RELATION AMONG MINERALS AND ARRANGEMENT OF MINERALS

Skarn deposits in contact metamorphic zones are usually analyzed on the basis of mineral paragenesis. However, as stated above, skarns are assemblages of silicate minerals of Ca, Mg, Fe, Mn, and include deposits which differ in origin. Hence, assemblages of minerals called skarns can be genetically classified as follows:

Reaction-skarn

Where iron ore deposits in limestone and dolomite are subjected to violent regional metamorphism, carbonates in the ore beds and their margins react with one another resulting in the formation of skarn minerals. Lindroth and Magnusson considered this to be the origin of skarns accompanying iron ore deposits in central Sweden, and they applied the term reactive-skarn. No special supply of substances is required from magma in the formation of this type of skarn.

Recrystallized Skarn

This is a skarn of the hornfels type produced as a result of recrystallization of impure limestone containing Si, Al, Fe, etc., marl, and calcareous tuff which were subjected to thermal metamorphism or dynamic metamorphism. Genetically, this resembles a reaction-skarn. In the case of coarse-grained silicate minerals of Ca, Mg, Al, etc., it is not easy to distinguish whether the skarn was formed by recrystallization or by metasomatism. In general, the structure of the original rocks remains distinct. (Examples: various places in the contact zone of the Chichibu Paleozoic system).

Primary Skarn

This is a skarn produced by mutual reaction along the boundary plane when intruded magma came in direct contact with carbonate rocks. In this case Si, Al, etc., were supplied from molten magma to carbonate rocks and Ca or Mg was supplied from carbonate rocks to magma. As a result, various skarn minerals are found mostly in a zonal arrangement along the boundary plane to an extent of several centimeters.

Tilley, in his study of the contact zones of Skye, designated this as primary skarn. (Examples: There are almost no skarns of this type in Japan. Hideo Kobayashi noted one in the Hida metamorphic zone, and the writer observed one in the marginal part of an aplite dike cutting limestone in Hirao-dai.)

Secondary Skarn

This is a skarn formed where limestone, magnesian limestone, and other calcareous rocks were replaced by a high temperature fluid (gaseous or liquid) released from magma, and in many cases it is accompanied by ore minerals. This is also called a replaced skarn or an ore skarn. Skarns of this type are mostly developed in the contact zone of an igneous rock mass, but sometimes in the interior of the igneous rock mass or outside in the surrounding rocks. Skarns within the igneous rock mass are termed endomorphic skarns around the contact part are termed exomorphic. Most skarns in the contact deposits belong to this type.

When volatile substances such as boron, fluorine, and chlorine are involved in the formation of secondary skarns, pneumatolytic skarn minerals containing these elements are produced. For example, in limestone are produced axinite, danburite, scapolite, and fluorite, in abundance. Skarns in magnesian limestone are frequently paragenic with ludwigite, chondrodite, etc.

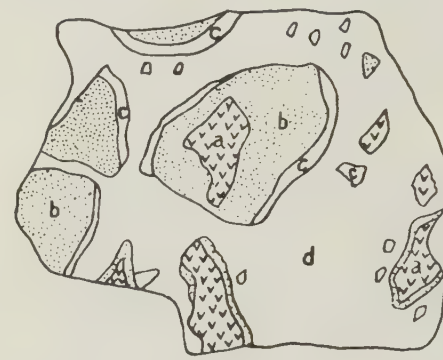

FIGURE 1. Brecciated skarn in the Kamaishi ore deposit (Sahinai ore deposit). Minerals reveal the order of their formation.

a) Garnet of the early period

b) Magnetite of the early period

c) Garnet of the later period

d) Magnetite and epidote of the later stage.

As magnesian carbonate rocks are scarce in contact zones in Japan, few examples have been reported. However, boron minerals accompanying skarns in limestone have been reported from various places.

The paragenic relation of the various skarn minerals is shown in Table 1. In this table examples of rhodochrosite are added as special examples in the item of original rock. As various manganese skarn minerals are contained in the manganese deposits in the contact zones in Japan, they are summarized based on the examples which have been reported to date.

Zonal arrangement of skarn minerals is typical. Minerals formed at the same time by diffusion are regularly arranged like primary skarns. However, ore skarns are not always syngenetic, that is, crystallization takes place in a definite sequences (fig. 1). In this case skarn minerals are mostly arranged as indicated in Table 2.

TABLE 1. Paragenetic relation of skarn minerals

Original rock	Unmeta-morphosed zone	Contact zone (Recrystallized)	Primary skarn	Secondary skarn (Silicate mineral)	Ore skarn containing B. F. minerals	Metallic minerals
Limestone	Calcite (Impurities) Clay Quartz, etc.	Calcite Grossular-andradite Wollastonite Diopside-salite Clinozoisite-epidote Amphibole	Grossular-andradite Clinozoisite-epidote Diopside-salite Sphene Calcite Plagioclase	Wollastonite Grossular-andradite Salite-hedenbergite Actinolite Ilvaite Clinozoisite-epidote Apophyllite Calcite	Axinite Vesuvianite Danburite Datolite Paigeite Tourmaline Fluorite	Gold Magnetite Hematite Pyrite Pyrrhotite Cubanite Chalcopyrite Stannite Cassiterite Scheelite Uraninite Sphalerite Galena Bismuthinite Molybdenite
Dolomite	Dolomite Calcite (Impurities) Clay Quartz etc.	Dolomite (Periclase) Brucite Calcite Forsterite Chondrodite Diopside Tremolite Talc Serpentine Phlogopite Spinel Geikielite Ilmenite	Forsterite Spinel Grossular-andradite Diopside-salite Tremolite Serpentine Wollastonite Sphene Calcite Plagioclase	Wollastonite Grossular-andradite Diopside Tremolite Talc Serpentine (Brucite) Vesuvianite Calcite	Kotoite Suanite Ludwigite-Paigeite Warwickite Fluoborite Szaibelyite Humite Chondrodite Clinohumite Fluorite	Gold Bismuthinite Magnetite Pyrrhotite Cubanite Chalcopyrite Sphalerite
Rhodo-chrosite deposit	Rhodochrosite Mn-calcite Mn-oxides (Impurities) Clay Quartz Neotocite etc.	Rhodochrosite Manganosite Pyrochroite Rhodonite Pyroxmangite Mn-hedenbergite Tephroite Galaxite Pyrophanite Spessartite Bementite Barite Hausmannite Braunite	Spessartite Tephroite Rhodonite Pyroxmangite Galaxite Pyrophanite Allanite	Tephroite Rhodonite Pyroxmangite Bustamite Mn-hedenbergite Dannemorite Mn-tremolite (Celsian) Hyalophane Ba-adularia Bementite Neotocite Mn-calcite	Alleghanyite Mn-axinite Pyrosmalite	Molybdenite Hübnerite Pyrrhotite Pyrite Cubanite Chalcopyrite Sphalerite Galena Alabandite

Based mainly on Japanese examples; Entries in parentheses not yet reported.

TABLE 2. Zonal arrangement of ore skarns

Location	Rock	Ore		Porphyrite	
Kamaishi	Limestone	Cu-sulphide ores Hedenbergite Actinolite	Magnetite Grossular-andradite	Grossular Epidote-clinozoisite	Granodiorite
Nakatatsu	Limestone	Coarse-grained calcite Wollastonite	Diopside-hedenbergite Sphalerite	Grossular-andradite	Hornfels or porphyrite
Ofuku	Limestone	Wollastonite	Hedenbergite	Andradite	"Granite"
Miyako Kamineichi	Dolomite	Cu-Sulphides Forsterite Clinohumite Kotoite-marble	Diopside Tremolite Phlogopite Talc Cu-Fe-Sulphides	Wollastonite	Quartz

CONTACT METAMORPHIC AUREOLES IN JAPAN AND CHARACTERISTICS OF METALLIFEROUS DEPOSITS IN AUREOLES

In Japan, the regions where Paleozoic and Mesozoic rocks and metamorphic rocks of unknown age occur are divided, according to the mode of regional metamorphism, into the following zones: the Hidaka metamorphic zone, the Kitakami axial metamorphic zone, the Abukuma metamorphic zone, the Hida metamorphic zone, the Ryoke metamorphic zone, the Sangun metamorphic zone, the Sambagawa metamorphic zone, the zone of unmetamorphosed Chichibu Paleozoic formation, and the zone of unmetamorphosed Mesozoic formation.

In these regions various acidic or neutral plutonic or hypabyssal rock masses are present, which were intruded in the late Paleozoic, the Cretaceous, the late Mesozoic-Paleogene, the Neogene, etc. Many of the rocks surrounding these rock masses were affected by heat at the time of intrusion and locally suffered thermal metamorphism. In general, where rocks intruded by plutonic or hypabyssal rock masses are unmetamorphosed or have suffered a slightly regional metamorphism, the parts subjected to thermal metamorphism are easily distinguished and the contact metamorphic zones easily observed.

Contact metamorphic zones, according to the metamorphic conditions of slaty rocks, are classified in order from the outside as follows:

I. Spotted slaty hornfels zone
II. Biotite hornfels zone
III. Cordierite-biotite hornfels zone

Carbonate rocks are re-crystallized by thermal metamorphism, limestone changes into crystalline limestone and exhibits a marble-like appearance.

Magnesian limestone is recrystallized as is limestone and changed into white crystalline marble. The marble, by more intense thermal metamorphism, is changed again into periclase marble or brucite marble. In Japan, no thermal metamorphic rock of this type has been reported.

At manganese deposits in rhodochrosite in the Chichibu Paleozoic formation, the rhodochrosite is changed to crystalline rhodochrosite in the contact zone, and locally, losing CO_2, is changed into manganosite. On the whole, combined with H_2O, it has been changed into pyrochroite ore. However, it is difficult to distinguish local thermal metamorphic zones in regions subjected to intense regional metamorphism.

In the metamorphic zones of Hida, the axial part of Kitakami, Abukuma, Ryoke, Hida, etc., extensive thermal metamorphic zones were formed due to regional dynamic metamorphism and later thermal metamorphism of the plutonic type with the result, that subzones of the metamorphic zones are complicated.

In such regions, after dynamic and thermal metamorphism occurred, igneous rock was

intruded in places. Here too, it is difficult to distinguish contact metamorphic zones formed by the new igneous rock intrusion.

Next, the relation between the metalliferous deposits in these contact metamorphic zones and granitic intrusive rock masses will be considered. In many cases, metalliferous deposits are found concentrated in contact zones not near the gigantic batholithic mass of granite but near somewhat small bosslike intrusive rock masses. The "granite" masses in Hananoyama and Ofuku, Yamaguchi Prefecture, are good examples.

In fact, there are few important deposits in the acidic plutonic rocks, gneisses, and contaminated rocks in areas of gigantic batholithlike granites such as occur in the Chugoku district, the Ryoke metamorphic zone, the Hidaka metamorphic zone, etc.

This fact perfectly coincides with results obtained by W. H. Emmons and others who studied the relationship between batholithic plutonic rock masses in the world and the distribution of ore deposits. That is, metalliferous deposits are not found so much in the interior of batholiths or their walls as at small proturberances or tips of the upper parts of batholiths. Consequently, metalliferous deposits are abundantly found not only near necks, apophyses, dikes, and small bosses but they also occur as vein groups in the hornfelsized parts in the upper parts of subterranean batholites. The groups of tungsten veins in Kaneuchi and Wachi are good examples.

Although the Kamioka deposit group formed by the replacement of limestone between intruded gneisses in the Hida metamorphic zone may appear inconsistent with this conclusion, according to recent investigators, the igneous rocks related to the Kamioka deposits are not the granites related to gneisses of the area but a yet unexposed igneous rock mass considered to be the source of granite-porphyry dikes. If this is correct, then even Kamioka would be no exception.

Support for the following thesis is growing: The cupriferous iron sulphide deposits (for example, Hitachi) in the marginal part of the granitic batholithic masses in the Hidaka metamorphic zone and the Abukuma metamorphic zone genetically have close relation to the basic igneous rocks which occur near the deposits older than the granitic rocks.

Moreover, the manganese deposits and the iron-manganese deposits in the Ryoke metamorphic zone and the Abukuma metamorphic zone may probably have resulted from ore beds connate with the metamorphic rocks, together with the country rocks, being subjected to regional metamorphism and thermal metamorphism of the plutonic type.

The general relationship between the contact metamorphic zones in Japan and ore deposits is characterized as described above. Detailed investigation of regional relations shows there are locally varying characters in the paragenesis of metals in the deposits, types of deposits, periods of formation of deposits, etc.

Individual peculiarities are summarized in the following eleven regional descriptions.

Hidaka Metamorphic Zone

As described above, in this zone there are pyrrhotite deposits containing cobalt, nickel, copper, etc. genetically related to a basic rock mass. These deposits may probably have been present before the intrusion of granites. It has not been revealed in full whether or not metalliferous deposits accompanied by skarns are present.

Southwestern Part of Hokkaido

This region is considered geologically an extension of the inner zone of Northeastern Japan. The Chichibu Paleozoic formation which is the basement is traversed by granites considered to be late Mesozoic, and deposits accompanied by skarns are rare in Hokkaido. The Katsuraoka magnetite deposits recently discovered are accompanied by skarns which replaced calcareous schalstein. The deposits are considered contact metasomatic deposits formed after the intrusion of granite, but there is an alternate view. According to Narita, the Katsuraoka deposits are genetically associated with diabase and formation of skarns seems not to be related with the intrusion of granite.

The Paleozoic formation in Oshima Province in this region seems to belong to the Permian chert zone, and some of the manganese deposits associated with the chert zone have been skarnized. Moreover, hausmannite which is considered to have been produced from chocolate-colored ore by thermal metamorphism has been discovered by Masao Ishibashi.

Inner Zone of Northeastern Japan

The basement of the green tuff region extending from Aomori Prefecture to Niigata and Nagano Prefectures, much the same as the above-mentioned southwestern part of Hokkaido, consists of older rocks related to the Chichibu Paleozoic formation and granites which traverse them. These rocks are exposed fragmentally among the younger formations in various places. In Aomori Prefecture and the northern part of Akita Prefecture some iron deposits and magnetite deposits of the skarn type have been known, which were formed by limestone replacement as seen in Toei and Kenashiyama. The Mochikura Mine in Niigata Prefecture is a typical copper deposit of the skarn type. Iron ore deposits associated with skarns of the contact

metasomatic type are found near granites as shown by the Sennin Mine in the western part of Iwate Prefecture and the Akatani Mine in Niigata Prefecture. In these areas younger rhyolites inferred to be Neogene are present. The hematite deposits which are considered the main deposits have been regarded as the products of igneous activity of the younger period, and these areas have been complicated by two periods of mineralization.

In the mountainland of the northwestern part of Fukushima Prefecture the chert zone of the Paleozoic formation is tranversed by granites. Manganese deposits scattered in the contact zone near this chert zone are deposits of the skarn type accompanied by tephroite, rhodonite, and hausmannite, and these are regarded as thermal metamorphic products of manganese carbonate ore.

Manganese deposits in the chert zone of the Ashio Mountainland extending over the two prefectures of Tochigi and Gumma are traversed by granodiorites exposed in Sawairi and east of it, and the deposits in the contact zone distinctly have been subjected to thermal metamorphism. In the Kaso deposits studied by Toyofumi Yoshimura are present manganese ore of the recrystallization type consisting of banded manganese carbonate ore, manganosite (partly pyrochroitized), tephroite, alleghanyite, rhodonite, galaxite and spessartite, and manganese skarn of the metasomatic type, partly replacing the former and consisting of coarse-grained tephroite, rhodonite and pyroxmangite. The latter type is accompanied by small quantities of sulphide minerals such as alabandite, pyrrhotite, and chalcopyrite and rarely hübnerite. Quite recently uranium ore associated with molybdenite was discovered by Hirowatari in the country rock of manganese deposits.

Abundant manganese ore deposits have been discovered in the contact zones in this district, that is, the deposits of Takabira, Satsuki, and Hagibira. In Hagibira, hübnerite was discovered by Fumitoshi Hirowatari. Peculiar manganese deposits containing pyrosmalite rich in Cl are also present as seen in the Kurasawa manganese deposits in Ashio-machi, and in the non-metamorphic rocks outside the contact zone manganese deposits of the Manago type which consist mainly of unmetamorphosed manganese carbonate ore. As to the conditions of thermal metamorphism of the manganese deposits in this area, a sequence of changes can be observed in the deposits of Nakanoyama, Hanawa, Higashikonaka, and Hagibira south of Sawairi.

The granite zones in Sawairi and other places in the Ashio Mountainland are areas where tungsten and molybdenum were concentrated. Fissures in quartzite and slates near the contact zone are filled with small veins of tungsten and molybdenum. In Itani there is a high temperature deposit accompanied by scheelite. The occurrence of hübnerite in part of the manganese deposits in this district is evidence that manganese released from granitic magma was absorbed by the manganese ore and adhered to it.

The Chichibu Paleozoic formation area extending over the western part of Tochigi Prefecture and the southern part of Ibaraki Prefecture is also a manganese deposit area associated with the chert zone like the Ashio Mountainland. The tungsten ores in Takatori are vein deposits formed during intrusion of the granodiorite mass lying to the northeast. The adjoining country rock is brittle and altered to hornfels. In the vicinity of Tsukuba-san skarns are found, in Yamanoo and other places, resulting from replacement of small limestone bodies in the Paleozoic formation, and contact metasomatic deposits associated with scheelite have been prospected in some other places.

In short, in the basal rocks underlying the Tertiary formation in the green tuff contact metamorphic zones are found in several places and various deposits accompanied by ore skarns are present. Older manganese deposits associated with the chert zone have frequently been subjected to thermal metamorphism. If, in the distant future, the basal rocks covered by younger beds and volcanic rocks are prospected, workable contact metasomatic deposits should be discovered in this area.

Kitakami Mountainland

In the Kitakami Mountainland, Paleozoic rocks (Devonian - Permian) and Mesozoic rocks from (Triassic - Cretaceous) are extensively developed. Penetrating these sedimentary rocks, small batholithlike and bosslike granites are exposed in various places. These rock masses, except for the Paleozoic Higami granite mass, are mostly considered to have been intruded after Jurassic or in the middle Cretaceous, and these masses gave rise to the formation of many ore deposits.

In the Kuji-Komaishi zone in the northeastern part of the Kitakami Mountainland the Paleozoic formations, belonging to the zone of chert which is probably Permian, are extensively distributed, intercalated with schalstein and limestone in places. These formations are traversed by bosses and small batholiths of granodiorite. In the limestone in the contact metamorphic zone are molybdenum contact metasomatic deposits as seen at Okawame and groups of large deposits such as copper of Ōminé and copper-iron of Kamaishi. Skarns accompanied by these deposits mainly consist of andradite, hedenbergite, etc. In the limestone zone near Miyako magnesian limestone predominates, and in Kamineichi dolomite is mined. In this vicinity dolomite was subjected to thermal metamorphism by the

Miyako granite mass and a peculiar metasomatic rock containing various magnesium boron minerals resulted. The country rock in Kamaishi exhibits the characteristics of southern Kitakami, but, as boron minerals are contained, it is described here.

A new locality of kotoite-marble discovered by the writer and Akira Kato is the third occurrence in the world to be reported. The first two are Chaktong [Holgol] in Korea and Rezbanya in Rumania. Kotoite is accompanied by borate minerals such as ludwigite, warwickite, suanite, fluoborite, szaibelyite, etc., and, though in small quantities, chalcopyrite, cubanite, pyrrhotite, etc. are contained. Minerals of humite series are common in the metamorphosed dolomite in this area.

Just south of Kamineichi is the magnetite deposit of Nejiro which was prospected during the war. This deposit has dolomite as a country rock. Such an association is rare in Japan, and this deposit is accompanied by magnesium skarn minerals.

At the time when the granites in the Kitakami Mountainland were formed diffusion of boron occurred extensively. The boron, as described above, occurs in the dolomite deposit as magnesium borate minerals, and in Kamaishi paigeite, a mineral of the ludwig series rich in iron, is found abundantly. Axinite is also common in this district.

In the chert zone along the limestone zone in the northern part of the Kitakami Mountainland are many bedded manganese deposits. The Noda-tamagawa manganese deposit south of Kuji is found in a hornfelsized roof pendant between two granodiorite masses. Chert in the country rock has been recrystallized and looks like quartzite. The slate interbedded with the chert has been changed into cordierite-biotite hornfels. The deposit consists of bedded or lenticular ore bodies, and has been intensely folded locally.

This deposit is inferred to have been originally a deposit mainly consisting of rhodochrosite, chocolate-colored ore, etc. as occurs in the non-metamorphic zone of the Paleozoic formation. However, the rhodochrosite was subjected to decarbonation by intense thermal metamorphism and has been changed into high-grade ore mainly manganosite and pyrochroite produced by the combination of manganosite and water. In the silicic part tephroite was formed and minerals in the part originated from chocolate-colored ore have been changed into ores consisting of coarse-grained hausmannite, manganosite, jacobsite, vredenbergite, and barite. In the somewhat silicic part braunite is present. Near the ore body is a small granitic dike, and the ore body is locally traversed by special pegmatite produced by assimilation of maganese. The pegmatite contains feldspar containing Ba and Se, alkali-augite, and hornblende and is accompanied by a special manganese mineral containing Sr, and Ti.

In the thin hornfelsized slate zone along the hanging wall of this manganese deposit uranium and vanadium are found. Uranium occurs as pitchblende and is accompanied by tourmaline, molybdenite, cobalt, and nickel minerals.

Moreover, small lenses of limestone lying side by side with this manganese deposit zone have been changed into marble, as may be seen in the vicinity of Shinyoneda pit, and the greater part of the limestone has been changed into blocks of common ore skarn consisting of garnet and hedenbergite both accompanied by sulphides of iron, copper, and zinc.

Not a few metamorphic manganese deposits like that in Noda-Tamagawa are found in the contact metamorphic aureole in this district. Besides the manganese deposits of Mitsune and others, many manganese skarn deposits are found in the vicinity of Kamaishi and Miyako.

In the middle part of the Kitakami Mountainland is a stratum containing ilmenite and magnetite which originated from iron sand, which having been metamorphosed in the contact zone, has been recrystallized.

In the Paleozoic formation occupying the southwestern part of the Kitakami Mountainland schalstein, limestone, slate (somewhat calcareous), etc. are found abundantly, and in the contact part of the granite mass traversing the Paleozoic formation there are many contact metamorphic deposits consisting of andradite containing much copper and iron, and ore skarn containing hedendergite. The Akagane copper deposit group is a good example. Some of these zones contain uranium ore. In this district, in the contact zone lacking limestone are veins of gold, tungsten (scheelite), and copper produced along the fissures. Gold has been mined in Shishiori and other places. The gold-tungsten mine of Setamai is a vein filling a fissure in limestone, and, probably due to formation at somewhat low temperatures, skarn is scarce and scheelite accompanies.

Abukuma Mountainland

In the main part of this mountainland, various metamorphic rocks produced by dynamic thermal metamorphism belonging to the Abukuma metamorphic zone are found, but no contact deposits or veins accompanied by significant skarns are found near the older granite mass. The limestones intercalated between the metamorphic

rocks have been partially skarnized, and there are some reaction skarns, recrystallized skarns, and primary skarns. In the vicinity of the younger granite mass skarn minerals containing scheelite were discovered by Keiichi Omori and others.

In Hayama west of the northern part of Fukushima Prefecture, ultrabasic rock overlies the granite mass as a roof pendant. Hasegawa discovered in the ultrabasic rock a peculiar boron-bearing metasomatic rock consisting of forsterite and ludwigite.

Some of the Mesozoic and Paleozoic rocks lying along the eastern part of the Abukuma Mountainland have not been subjected to much dynamic metamorphism, and yield Devonian-Carboniferous fossils. These formations are traversed by Cretaceous granites in the Mesozoic and various contact metamorphic rocks have been formed. The Takakura iron ore deposit west of Haranomachi is of the skarn type, but is accompanied by a small quantity of copper ore; magnetite is the principal ore mineral. The Yakuki deposit is a contact metamorphic deposit of copper and iron, accompanied by garnet, hedenbergite, and skarns. Recently a large ore body continuing to the deep part was discovered and is being actively worked.

The Hitachi ore deposit group in the southern part of the Abukuma Mountainland is a genetically complicated cupriferous iron sulphide deposit, like the Tarō deposit of Kitakami. The country rock is a metamorphic hornblende facies and is accompanied by cordierite- and anthophyllite-bearing rocks. The deposit consists of bedded, irregularly lenticular, or massive ore bodies. The deposit is warped along the fold of the metamorphic rocks cut by pegmatite and aplite dikes. South of the deposit zone is the Iruyama batholithic granodiorite mass. A cupriferous iron sulphide deposit is inferred to have existed before intrusion of the granodiorite mass which subjected it to multiple metamorphism. The Hitachi ore deposit is genetically of special interest as a deposit situated in the deep contact zone, though it is not a simple contact deposit.

Chichibu Mountainland

In the Chichibu Paleozoic zone of the Kwanto Mountainland a quartz diorite boss considered to have intruded Tertiary rocks is present. This boss seems to be a rock body solidified at a relatively shallow depth with only slight development of a contact zone. However, slate has been changed into hornfels and limestone into marble. Primary skarn is found also at the contact and ore skarn consisting of garnet and hedenbergite accompanied by magnetite, pyrrhotite, etc. is distributed in various places. However, the main deposit being mined is a complicated assemblage of ores containing gold, zinc, lead, and iron sulphide; a metasomatic deposit of low temperature hydrothermal type formed after the skarn. In the fissures near the deposit are found veins of lead and zinc of the low temperature hydrothermal type containing antimony minerals. Toshiya Miyazawa considers this to be a xenothermal contact metasomatic deposit. In Nagano prefecture, to the west of this area, iron and gold deposits accompany skarns near Nakakosaka. Near the Tanzawa quartz diorite mass, which is frequently compared with the Chichibu quartz diorite mass, are localities of vesuvianite-garnet skarn accompanied by monticellite which is considered primary skarn, and forsterite and clinohumite accompanying crystalline dolomite, but few important ore skarns have been found.

Ryoke Metamorphic Zone

In the region along the Median Dislocation Line in the inner zone of Southwestern Japan there is the Ryoke metamorphic zone which abounds in dynamo-thermal metamorphic rocks. Among these are conformable older acidic igneous rocks and younger intrusive rock bodies which cut them. Multiple metamorphic rocks are in abundance, but no significant contact metasomatic deposit have been found. In a quartzite zone between injection gneisses are bedded or lenticular deposits containing silicate minerals of manganese all inferred to have resulted from dynamo-thermal metamorphism.

In the Taguchi manganese deposits, rhodonite, pyroxmangite, tephroite, alleghanyite, manganosite, pyrochrolite, manganese spinel, dannemorite, spessartite, etc. are found in complicated paragenesis. Deposits of this type are recrystallized reaction manganese skarn deposits, of which Taguchi Mine and Dando Mine are representatives.

Unmetamorphosed Chichibu Paleozoics, Inner Zone of Southwestern Japan

North of the Ryoke metamorphic zone in Southwestern Japan is an unmetamorphosed zone consisting of Permian and Carboniferous rocks of the Chichibu Paleozoic formation. This region has not been subjected to intense dynamo-metamorphism. Here the mode of intrusion of acidic plutonic rock mass somewhat resembles that of the Kitakami Mountainland, that is, in the contact zone are thermal metamorphic rocks which have been hornfelsized. In the limestone contact metamorphic zone is ore skarn associated with sollastonite, hedenbergite, and garnet skarn. For example, in Permian limestone in the southern part of Ishikawa and Fukui Prefectures, there are the contact metasomatic zinc deposits of Nakatatsu and Bandojima and in the middle part of Gifu Prefecture there are many contact metasomatic deposits containing zinc and copper and accompanied by

skarns, such as those at Horado, Ebisu, Yatsubo, and Kinjo.

In the Funabushiyama-Ibuki district are Permian magnesian limestone and dolomite beds, containing magnesia skarn minerals which are relatively rare in Japan. The skarns of clinohumite, spinel, and garnet, in the contact zone in Tokiwa near Omachi, Nagano Prefecture, the diopside skarn in the Horado deposits, and the skarns containing minerals of wollastonite, diopside, humatite series in the Kasuga dolomite mine are good examples, but no large metalliferous deposits have been found.

In Kyoto Prefecture, the wollastonite, garnet, rhodonite skarns in the contact zone in Nyoiga-take and other places are well-known, but large contact metasomatic ore deposits are scarce. In the limestone-poor Tamba area, quartz veins containing high-grade wolframite and scheelite cut a biotite hornfels containing tourmaline. Kaneuchi and Wachi are examples.

The Chichibu Paleozoic zone in the western part of Matsumoto, Nagano Prefecture, the southern part of Gifu Prefecture, Shiga Prefecture, the southern part of Fukui Prefecture, the Tamba district, Kyoto Prefecture, and the southern part of Tottori Prefecture contains a so-called chert zone with many associated manganese deposits. As in the Kitakami Mountainland, these deposits in the contact zone have been recrystallized and manganese skarn minerals have been formed. The Goshirai Mine is representative, and in Osaka Prefecture is the Taga manganese deposit which was subjected to thermal metamorphism.

Extending from the middle-northern part of Okayama Prefecture to the northeastern part of Hiroshima Prefecture, the continuation of the above-mentioned Paleozoic formation, traversed by granites, is distributed intermittently. The limestone zone in this district is frequently traversed by granodiorite mass. In the contact zone skarns mainly consisting of andradite and hedenbergite are abundantly found, and, in Yamamuro and Kanahira, the skarns contain magnetite, pyrrhotite, and chalcopyrite, and arsenopyrite. At Yoshioka, the ore minerals occur in many veins in the limestone.

The geosynclinal sedimentary rocks in Yamaguchi and Fukuoka Prefectures, are intruded by the Hiroshima granite batholith which is exposed in isolated spots. Under the Paleozoic formation in this district are acidic igneous rocks, and granite and quartz porphyry dikes and small bosses irregularly cut the Paleozoic formation. To the extent of several hundred meters around the igneous rock mass there is a remarkable contact metamorphic zone where biotite hornfels and crystalline limestone are found.

In the region of Hiraodai and Akiyoshidai, the rocks consist mainly of a limestone called the Akiyoshi facies. Around the small bosslike granite intrusions, have formed many contact metasomatic deposits of copper and iron. Various metallic sulphide minerals are contained in ore skarns, mainly wollastonite, hedenbergite, garnet, and livrite. In the contact part of Hananoyama in the southern part of Akiyoshidai, studied by Takeo Kato, are the copper ores of Ota, Eboshi, and Hananoyama, and in the skarns of Nagato deposits somewhat distant from the contact zone, are minerals of copper and cobalt. Besides these, in this district there are the copper contact metasomatic deposits of Zomeki, Asahi, Kawaiyama, and Ofuku and the deposits of Sasagatani and Tomo, Shimane Prefecture. In the southern part of Hiraodai in Fukuoka Prefecture, North Kyushu, there are many copper deposits such as Yoshiwara, Takaradai, Tatsuta, and Sanno-take. These are all in almost the same paragenic relation.

The Paleozoic formation west of Iwakuni is in the north side of the Ryoke zone. It has been intruded by granites in various places, and this area shows many features of roof pendants. The Paleozoic formation in this area may probably correspond with the Permian chert zone. Lenticular limestone occurs between silicic hornfels produced due to quartzitization of chert and the biotite hornfels zone which originated from slate. These limestones have been changed into marble by thermal metamorphism due to the intrusion of acidic igneous rock mass, and the marble has been replaced by ore skarns containing tin, tungsten, and copper produced by mineralization following the above-mentioned thermal metamorphism. In this area there are the Kiwada deposit which produced scheelite and cassiterite, and the deposits of Kuka and Fujigaya. The skarn ore bodies, being controlled by the form of limestone, are developed along an E-W fold axis. In the vicinity of the skarn ore bodies quartz veins are developed accompanied by scheelite. These quartz veins may probably have filled fissures which were passages of mineralized fluid in which tungsten and tin were carried.

In the quartzite zone in this area, in the same manner as in other chert zones, many manganese deposits are found. Between the country rocks which have been hornfelsized are manganese skarns inferred to have been subjected to thermal metamorphism, and between the skarn minerals tungsten minerals, hübnerite, and sulphide minerals of copper and iron are found. These minerals are considered to have been supplied in the course of high temperature metasomatism. The manganese deposits of Kusugi, Renge, Takamori, and Fukumaki are deposits of manganese skarn type showing the paragenesis of minerals which resemble those of Kaso, Ioi, and Nodatamagawa. In short, this area is mineralogic-

ally interesting as an area where lime and iron skarns are found mixed in the same metamorphic zone. These skarns are replacements of limestone and manganese skarn ores which in turn had replaced manganese carbonate ore.

Lastly the iron sulphide deposit of the Yanahara type in this area will be mentioned.

The genesis of this deposit has long been a topic of debate. Takeo Kato considered this iron sulphide to be a metasomatic deposit produced in the high temperature hydrothermal period after the intrusion of granite. On the other hand, Mikio Kuhara regarded it as being due to magmatic differentiation of the igneous rocks which occur near the deposit. The Yanahara deposit, together with the country rock, is cut by dikes of granite porphyry. The ore bodies have been metamorphosed near the dikes, and pyrite has been changed into magnetite and pyrrhotite. The margin of the main ore body in Yanahara is surrounded zonally also by magnetite and pyrrhotite. As a whole, this deposit seems to have been subjected to the influence of the intrusion of granodiorite extensively exposed to the north. Most of the ore bodies in Yanahara mine are limited to a special stratum called the volcanic complex zone. It is considered that massive iron sulphide of the low temperature type was recrystallized by the intrusion of granite. In either case, as to the genesis of this deposit, many problems remain unsolved, but this deposit is mentioned as an example of iron sulphide deposits.

Sangun Metamorphic Zone

In the middle parts of North Kyushu and the Chugoku district are extensive phyllitic or schistose crystalline rocks produced by dynamic metamorphism of low degree (early Mesozoic) of the Paleozoic formation. The metamorphic zone in this region is called the Sangun-Motoyama metamorphic zone. The Cretaceous Hiroshima granites intruded and exercised metamorphism again on this region. The Kawayama cupriferous iron sulphide deposit in the middle course of the Nishiki-gawa in this region has been regarded as a fissure-filling deposit along a shear zone in the weakly metamorphosed rock. In the vicinity of the deposit is an intruded rock body of quartz porphyry, and crystalline limestone lies adjacent to the ore body. In the limestone is a massive deposit associated with garnet, hedenbergite, and ore skarns. The fissure-filling deposit has been partially changed into a high temperature metasomatic type deposit. In this respect, it resembles the deposit in Yoshioka. There are some manganese deposits in the Sangun metamorphic zone west of Fukuoka. As seen in the Iwaki deposit, manganese skarn ore associated with jacobsite was discovered in the vicinity of the younger granite.

Hida Metamorphic Zone

In the north side of the unmetamorphosed Paleozoic formation in the inner zone of Southwestern Japan is an area called the Hida metamorphic zone, consisting of crystalline schist, injection gneisses, and granites. Highly metamorphosed rocks are intercalated with lenticular or bedded limestone. These limestones have been changed into crystalline limestone and locally graphite is contained. Moreover, various skarn minerals (silicate minerals of Ca-Mg) are also contained. For example, like the contact zone between the Moriyasu granite and limestone studied by Hideo Kobayashi, skarns are zonally arranged in the contact zone in the following order: first, limestone, then diopside, garnet, and wollastonite, then augite-bearing rock, then augite-bearing hornblendite, than a hornblende-biotite zone, and finally granite. These can be considered metasomatic zonal skarns having characteristics of primary skarns, but differ from skarns associated with ores,

In the Tochibora deposit of the Kamioka Mine and in the vicinity of the adjacent Inishi Pass, a syenitic rock intercalated with lenses of limestone is found. In the boundary between the limestone and syenite a narrow skarn zone consisting of syenite - garnet - diopside is developed, locally accompanied by chondrodite. The ore skarns which constitute the Kamioka deposit are different mineralogically from the above-mentioned skarns. The skarns of the Kamioka deposit are hedenbergite skarns which are mainly aggregates of coarse-grained columnar crystals. Such skarns are called "mokuji" in the mine. These skarns are associated with lievrite and garnet, contain sulphide minerals such as zinc and lead, characteristic of ore skarns. In Kamioka there is also a white metasomatic deposit containing hydrothermal quartz, calcite, etc. This deposit is called "shiroji" in the Kamioka Mine. Many have consider that mineralization of the Kamioka deposit group took place after the metamorphism of the end of the Paleozoic. However, recent researchers consider that the ore skarns in Kamioka were produced in a much later period than the injection gneiss, that is, mineralization took place during the injection of quartz porphyry which cuts the Tochibora deposit. It is inferred that the parental magma from which the deposit originated is deep beneath the deposit zone, but a contact metamorphic zone to confirm this inference cannot be found. Hence, as far as we know, in the Hida metamorphic zone believed to be Precambrian, there is no ore deposit considered to have been produced in the metamorphic age except graphite deposits.

Outer Zone of Southwestern Japan

No acidic plutonic rocks intruded the Sambagawa metamorphic zone, hence there is no contact metamorphic zone. However, the

Paleozoic and the Mesozoic zones outside the above metamorphic zone are cut by younger possibly Tertiary acidic rock bodies in places. Around the rock bodies are found many contact deposits. The Paleozoic zone in the upper course of the Kumano River, Nara Prefecture, is traversed by granite, and the Horakawa deposit and many other skarn type iron deposits have been formed in limestone. The deposits are associated with garnet and hedenbergite and contain magnetite, pyrrhotite, and chalcopyrite.

There are no significant deposits in the contact zone in the Uwajima granite in Shikoku but in Kyushu there is a large deposit area centering on Okuzure-yama, known as the Obira metallogenetic province, which yields tin, lead, zinc and copper. In the limestone area are many multiple metalliferous skarn deposits, such as Obira, Toroku, Kiura, and Mitate, now being mined.

In the skarn deposits occur tin, zinc, and lead, and in one and the same area are found high temperature type skarn deposits containing cassiterite, pneumatolytic vein or moderate temperature hydrothermal type copper and arsenic deposits, and zinc-lead deposits. In this area are many hedenbergite-garnet skarns, and boron minerals, such as dacolite, danburite, and axinite, are produced abundantly.

Around a small granite mass near Taniyama in the southern part of Kyushu there are veins and skarn type tin deposits.

In Yaku-shima tungsten veins are found in the hornfels zone in the zone of contact with the porphyritic granite mass. In this area there is no limestone on a large scale.

In the Paleozoic formation of Southwestern Japan there are parts which are rich in limestone and parts which are rich in chert. In the chert zone southwest of Tsukumi City in the southern part of Oita Prefecture there are many manganese deposits. As stated above, the deposits were subjected to the effect of thermal metamorphism in the vicinity of the granite mass, and have become a manganese skarn.

In the Okuzure-yama granite mass and associated cupriferous iron sulphide the effect of thermal metamorphism appears with increase in depth.

In the upper partly mainly pyrite is found, downward it passes into a deposit consisting mainly of pyrrhotite. In the lower part, cubanite is abundantly found.

SUMMARY

Of metalliferous deposits in contact metamorphic aureoles, deposits associated with skarn are the most remarkable. The deposits are simply called contact deposits and are regarded as the representative.

However, whether a skarn is formed or not in the contact metamorphic aureole is dependent on whether limestone or dolomite exists in the original rock. In non-limestone areas, instead of contact deposits, high temperature veins or impregnation deposits are formed.

Aggregates of minerals called skarns are genetically complex. Skarns are genetically classified into -

1) Reaction skarn

2) Recrystallized skarn

3) Primary skarn, and

4) Secondary skarn (ore skarn).

The important skarns accompanying the metalliferous deposits in Japan are secondary or ore skarns.

Paragenesis of skarn minerals differs considerably depending on original rock. For example, limestone, dolomite, rhodochrosite, and calcareous tuff show characteristic paragenesis. It goes without saying that paragenesis varies with the substances supplied from magma.

The regional characteristics of the skarns of the metalliferous deposits in Japan are summarized in Table 3.

The skarns of the contact metasomatic metalliferous deposits in the contact zones in Japan are characterized by skarn minerals unique to limestone zones.

The formation of manganese skarns due to contact metamorphism of manganese carbonate ore in the chert zone is also an interesting phenomenon characterizing manganese deposits in Japan.

TABLE 3. Summary of metalliferous skarn deposits in Japan

	Characteristics of metamorphism	Lithologic Characteristics * - Common	Type of deposit in the contact zone: Pneumatolytic vein	Hydrothermal vein	High temperature metasomatic deposit	Hydrothermal metasomatic deposit	Contact metamorphic deposit	Skarn: Reaction skarn	Recrystallized skarn	Primary skarn	Secondary (Ore) skarn	Example of principal ore deposits
I. Hida metamorphic zone	Areal Plutonic Thermal	Non-calcareous*	-	-	-	-	-	-	-	-	-	?
II. Southwestern part of Hokkaido	Unmetamorphosed Thermal	Limestone	-	-	+	-	-	?	-	-	+	Katsuraoka (Fe)
		Magnesian limestone	-	-	-	-	-	-	-	-	-	
		Slate*	-	-	-	-	-	-	-	-	-	
		Chert* Manganese ore*	-	-	-	-	+	-	+	-	-	Omatsumae (Mn)
III. Inner zone of Northeastern Japan	Unmetamorphosed Thermal	Limestone	-	-	+	+	-	-	+	?	+	Mochikura (Cu)
		Slate*	+	-	-	-	-	-	-	-	-	
		Chert* Manganese ore*	-	-	-	-	+	-	+	-	+	Northwestern part of Fukushima Pref. (Mn) Ashio Mountainland (Mn) Kaso (Mn,U) Kurasawa (Mn)
IV. Kitakami Mountainland	Unmetamorphosed Thermal Weak dynamic	Chert* Manganese ore*	+	-	+	-	+	+	+	+	-	Noda-tamagawa (Mn, U) Mitsune (Mn)
		Limestone*	-	-	+	+	-	-	-	?	+	Kamaishi (Fe, Cu) Yamaguchi (Cu, U) Okawame (Mo) Mukuromi (Au, As)
		Magnesian limestone	-	-	+	-	-	-	-	+	+	Miyako-Kamineichi (B, Cu) Neshiro (Fe)
		Non-calcareous	+	+	-	-	-	-	-	-	-	Setamai (Au, W)
V. Abukuma Mountainland	Regional Plutonic Thermal Unmetamorphosed	Quartzite*	-	-	-	-	+	-	-	-	-	Gozaisho (Fe, Mn)
		Limestone*	-	-	+	-	-	+	+	+	+	Takanuki district (W) Takakura (Fe Yakuki (Cu, Fe)
		Magnesian limestone	-	-	-	-	-	-	+	-	+	Hayama (B)
		Non-calcareous*	-	-	-?	-	+	-	-	-	-	Hitachi (Cu, FeS_2)

VI. Chichibu Mountainland	Unmetamorphosed Thermal	Chert* Manganese ore*	+	+	-	-	+	-	+	-	+	
		Limestone*	-	+	+→	+	-	-	+	+?	-	Chichibu (Fe, FeS_2, Cu, Zn, Pb, Au)
		Magnesian limestone	-	-	-	-	-	-	-	-	-	
		Non-calcareous*	-	-	-	-	-	-	-	-	-	Chichibu (Zn, Pb, Sb)
VII. Ryoke metamorphic zone in Southwestern Japan	Regional Plutonic Thermal	Quartzite* Manganese ore*	-	-	+	-	+	+	+	-	+	Taguchi (Mn)
		Limestone	-	-	-	-	-	+	-	-	-	
		Magnesian limestone	-	-	-	-	-	-	-	-	-	
		Non-calcareous*	-	-	-	-	-	-	-	-	-	
VIII. Chichibu complex unmetamorphosed zone, Southwestern Japan	Unmetamorphosed Thermal	Chert* Manganese ore*	+	+	+	-	+	-	+	-	+	Ioi (Mn, U) Iwakuni district (Mn)
		Limestone*	+	-	+	+	-	-	+	+?	+	Nakatatsu (Zn, Pb) Sasagatani (Cu) Sambo (Fe) Kiwada-Fujigatani-Kuka (W) Jamampuama (Cu)
		Magnesian limestone*	-	-	-	-	-	-	+	-	+	
		Non-calcareous*										
IX. Sangun metamorphic zone	Regional Plutonic Thermal	Quartzite Manganese*	-	-	-	-	+	-	+	-	+	Itsuki (Fe, Mn)
		Limestone*	-	-	+	+	-	-	-	-	-	Kawayama (FeS, Cu)
		Magnesian limestone	-	-	-	-	-	-	-	-	-	
		Non-calcareous* Basic*	-	+	-	-	-	-	-	-	-	
X. Hida metamorphic zone	Regional Plutonic Thermal	Limestone*	-	-	+	+	-	+	+	+	+	Kamioka (Zn, Pb)
		Magnesian limestone	-	-	-	-	-	-	+	-	-	Inishi-toge
		Non-calcareous*	-	+	-	-	+	-	-	-	-	Amafu (graphite)
XI. Outer zone of Southwestern Japan: Sambagawa-Mikabu metamorphic zone	Regional Non-thermal											
XI. Outer zone of Southwestern Japan: Unmetamorphosed zone	Weak regional ↓ Unmetamorphosed	Chert* Manganese ore*	-	-	-	-	+	-	+	-	+?	Kiura district (Mn)
		Limestone*	+→	+→	+ →	+	-	-	+	-	+	Obira (B, Sn, Cu, Pb, Zn, Ge) Toroku (B, Sn, As) Horakawa (Fe) Kiura (Sn, Cu)
		Magnesian limestone*										
		Non-calcareous*	+→+		-	-	+	-	-	-	-	Obira (Cu, Zn, Pb) Mitate (Sn) Taniyama (Sn) Makimine (FeS_2, FeS, Cu) Yakushima (W)

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CHEMICAL DISTINCTIONS BETWEEN THE THREE PRINCIPAL SERIES OF BASALTIC ROCKS[1]

by

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• *translated by Reiko Fusejima* •

ABSTRACT

A new diagram to permit analysis of the chemical composition and genesis of basalts is proposed, the wo-fo-Q diagram. Three major series of basalts are distinguished: alkaline rock series, tholeiitic rock series, and contaminated rock series. The Mauna Loa-Kilauea basalts and the Mull-Antrim basalts are both tholeiitic but differ in evolution. Basalts of Rishiri Island, Oshima-Ooshima in Hokkaido, and the Izu Islands are of the acid tholeiitic series, those of Izu Peninsula and Fuji Volcano are of basic tholeiitic series. The Izu-Hakone "parental magma" of Kuno differs from typical tholeiitic basalt. Indo-Chinese cenozoic basalts are of the contaminated rock series. "Tholeiitic basalts" of northern Kyushu are probably of the contaminated series. --M. Russell.

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CONTENTS

INTRODUCTION

The progress of atomistic petrology is remarkable nowadays and suggests a future trend of the science of rocks. On the other hand, many problems remain unsolved in the field of phase petrology, and further progress in this line is expected.

The most important phase petrological problems today concern granite batholiths, the origin of basaltic magmas and whether or not peridotite magmas exist. The writer has been studying these interesting problems and has noticed that the available data, in spite of their abundance, have not always been correctly interpreted or applied.

The present paper deals with the writer's interpretation of basaltic rocks, with emphasis on the olivine-pyroxene relations. The subject to be discussed here is merely a small, though fundamental, portion of the basalt problems. Many problems concerning basaltic rocks cannot be explained without a full understanding of the relationship between the chemical compositions varying with geologic age and the global distribution (petrographic provinces) of basaltic rocks, as well as knowledge of the origin of basaltic magmas. However, the writer will not discuss those problems until another opportunity is available.

METHOD OF STUDY

We are well aware that graphic representation of variations of chemical composition to be used in the study of magmatic evolution is diversified according to the student or to the objective of research. For the study of variations of chemical compositions the following three points must be kept in mind: 1) Intrinsic

[1] Translated from the Japanese: in Jubilee Publication in Commemoration Professor Jun Suzuki, M.J.A. Sixtieth Birthday (1956), p. 193-211, 1958.

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differences in the chemical compositions of the rocks to be studied should come out through any graphical methods. Hence, the aim of the diagrams representing the chemical compositions must not end with indication of differences but the diagrams ought to help genetical research of the rocks in question. 2) Chemical compositions must be compared by the results of normative calculations. This is indispensable especially for basaltic rocks having delicately variant chemical compositions. It must be remembered that comparison by the numerals of analytical data alone would often lead one to a dogmatic conclusion. 3) Examination of only one diagram would never suffice. Any diagram has its strong points and weak points, hence the intricate processes of magmatic evolution cannot be rightly understood without a comparative study of various diagrams.

Taking the above points into consideration, the writer comments on the following three diagrams [3]:

1. Normative an-ab-or diagram: No explanation may be necessary for this diagram. State of evolution of modal feldspar and composition variation of normative feldspar in liquid magma (Tomita, 1951, figs. 1-3) serve as a good reference to the present study.

2. Normative Q-fo-fa diagram: The diagram was conceived to determine the saturation of silicic acid in magma.[4] From this diagram the Mg-Fe relations (in case iron ores are excluded) are also known (Tomita, 1951). Whether or not the theory represented by the experimentally obtained equilibrium system Mg_2SiO_4 - Fe_2SiO_4 - SiO_2 (Bowen and Schairer, 1953) is applicable to the rocks in nature is an interesting subject for discussion.

3. Normative wo-fo-Q diagram (newly proposed): This diagram[5] includes di-fo-Q triangular diagram which corresponds to diopside-forsterite-silica equilibrium system (Bowen, 1914). The boundary between the forsterite zone and the pyroxene zone of this series is for the most part represented by the reaction line, and a small part near di is the eutectic line. In the crystallization process of the original fluid, if the course of the fluid in the forsterite zone crosses the reaction line, pyroxene forms by the reaction between forsterite and fluid, and if the crystallization course meets the eutectic point, diopsidic pyroxene crystallizes without said reaction. As is generally known, in the series of tholeiitic basalts, pigeonite or subcalcic augite forms by the reaction between olivine and liquid magma, whereas in the alkali basalt series no reaction relation is found between the coexistent olivine and pyroxene (diopsidic pyroxene or augite). For comparison of the fact in nature and the experimentally established equilibrium system, the boundary line stated above is plotted in the wo-fo-Q diagram (although it is inferred that the boundary in nature is not fixed, and some deviation may occur in each magmatic province).

Besides the afore-mentioned three diagrams, an interesting result is obtained by the normative Q-an relation diagram also.[6] The diagram of (K_2O + Na_2O)-TiO_2 relation is helpful in detecting slight variations of chemical composition which are discernible by other graphical representations.[7] However, systematic descriptions of these methods are omitted in this paper. The writer only emphasizes here that in the study of magmatic evolution considerations from all possible viewpoints are necessary.

TILLEY'S THOLEIITIC SERIES

Tilley (1950) considered that the basaltic lavas of Mauna Loa and Kilauea belong to one and the same evolution series which he named "tholeiitic series." According to him the series consists of the sequence of rocks, namely, tholeiitic picrite basalt -- tholeiitic olivine basalt -- basalt -- hypersthene basalt.

The chemical peculiarity of this series is

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[3] The method of normative calculation follows the American system (weight norm), not Niggli's molecular norm. The reason is, as explained later, for comparison with the equilibrium diagrams prepared from experimental data.

[4] Method of calculation: Taking an example where normative pyroxene is calculated as wo, en and fs, the values of en and fs are converted into 'fo' and 'fa,' and the residual SiO_2 is calculated as 'Q'. The resultant values are added to fo, fa and Q which were already calculated by the normal method, and then the respective percents are computed.

[5] Method of calculation: The fundamental principle of calculation is same as 2. However, Q is different from the case of Q-fo-fa, as only SiO_2 which is left behind after en was converted into fo, is used.

[6] In this diagram, the quantity of SiO_2 required for saturation of normative fo, fa, and ne is expressed as -Q; an is that in normative feldspar. The result of examination of volcanic rocks by means of this relation diagram was reported in the special lecture entitled "Magmatic evolution and its geologic backgrounds" delivered at the regular meeting of the West Japan Chapter of the Geological Society of Japan on July, 1, 1956.

[7] Examples are given in later section (refer to fig. 5).

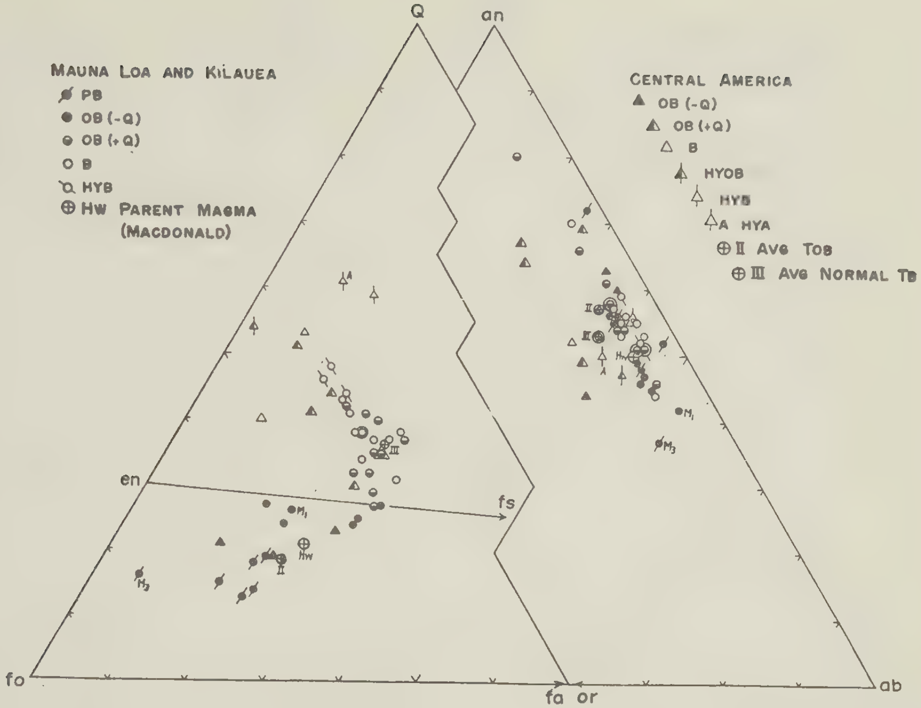

FIGURE 1. Mauna-Loa-Kilauea basaltic rocks and the Quaternary lavas of Central America (Mexico, Nicaragua, Panama, Martinique, St. Vincent), Abbrev.-PB, picrite-basalt; OB, olivine basalt; B, basalt; HYOB, hypersthene-olivine basalt; HYB, hypersthene basalt; HYA, hypersthene andesite; TOB, tholeiitic olivine basalt; TB, tholeiitic basalt

distinctly manifested in Figure 1.[8] The most noticeable characteristics are as follows: 1) The composition of mafic minerals shows regular and marked variations, whereas the feldspar varies little on the whole.[9] 2) In the Q-fo-fa diagram it deserves special attention that the tholeiitic basalt suddenly passes into hypersthene basalt on the upper left.[10] 3) It is noticeable that the hypersthene basalt is found in the terminal area where Q is most abundant.

In the wo-fo-Q diagram (fig. 2), the following interesting facts are noticed: 1) The series of olivine basalts starting from the parental magma of Macdonald crosses the reaction boundary line Rn which is a part of boundary line RNE. Thus, the olivine basalts are known to be tholeiitic. 2) In the zone of pyroxene-quartz, the distribution of the respective points is sporadic, showing no such regularity as would correspond to Figure 1.

For understanding the genetic significance of the above-mentioned chemical characteristics, study of much higher modes is necessary. With regard to the cause of the feature 2) observed in Figure 1, there are two probabilities as follows, although the writer refrains from discussing them in detail: a) On account of crystallization of iron ores in great quantities, the Fe content decreased, as far as this graphical

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[8] The diagram was prepared on the basis of the data by Macdonald (1949a). It shows the parental magma by Macdonald (1949b), the tholeiitic olivine basalt (II) by Nockolds (1954) and the normal tholeiitic basalt (III).

[9] By referring to the feldspar composition in other diagrams of this paper, this may be understood well.

[10] This sudden conversion is seen only in the Mauna Loa basalt. This fact is important for the study of the lavas of Hawaii Islands.

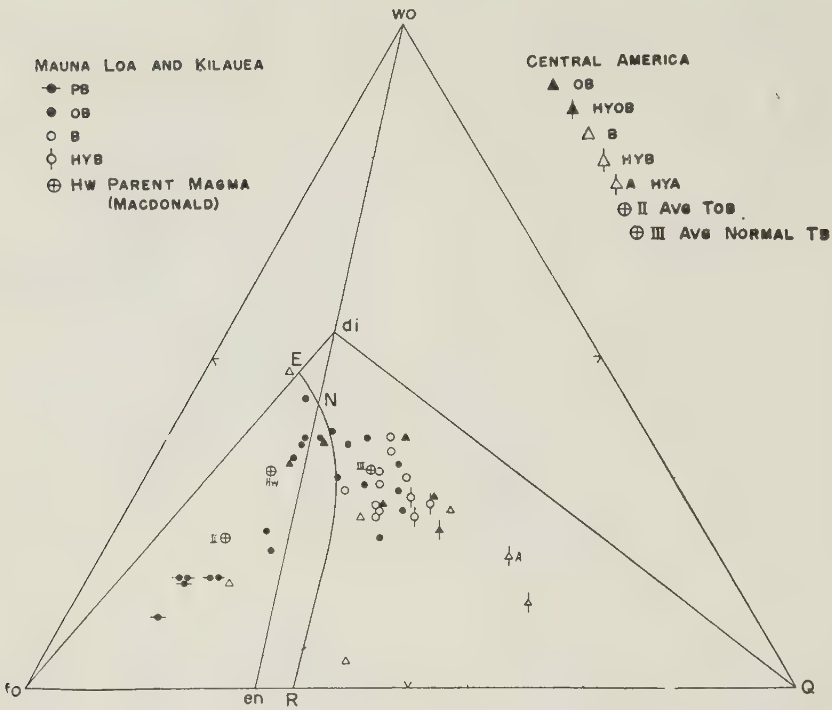

FIGURE 2. Mauna Loa-Kilauea basaltic rocks and the Quaternary lavas of Central America (Mexico, Nicaragua, Panama, Martinique, St. Vincent). Abbrev. refer to those given for Fig. 1.

method is concerned. 2) The Mg-Si content rapidly increased, as for example the Mg-Si content in the basic rocks[11] at depth was selectively assimilated.

ACID THOLEIITIC SERIES

In order to study the volcanic rocks of the Tertiary Hebridean-Irish region, basalts of Mull Island (Bailey, et al., 1924) and Antrim Plateau of Northern Ireland (Patterson and Swaine, 1955) have been treated (figs. 3, 4).

It is known that these basalts differ from the "tholeiitic series" of Hawaii in the following ways: 1) Variation of evolution of the feldspar composition is noticeably different. 2) None of the tholeiitic basalts of England ("non-porphyritic central magma-type" of Mull Island and tholeiitic basalt of Antrim district) shows the calcic plagioclase-rich type which is known in Hawaii Islands (however, it is found in the porphyritic central magma type of Mull Island). 3) Ferromagnesian minerals conducted evolution in accordance with the evolution of feldspar composition. 4) The variation of Q-fo-fa relation of the basalt of Mull Island shows the following characteristics: a) No sudden turn toward upper left, as is known in Mauna Loa, is seen, but rather a pass through the center of the diagram toward apex Q. b) On the way [T. N.; to the apex] is found the rock type denoted as "tholeiite" which contains feldspars of much later stage than the Hawaiian basalts. 5) The tholeiitic basalts of Antrim are more or less similar to the "tholeiitic series" of Hawaii. In a strict sense, however, they differ from the latter in two points: a) Many of normative feldspars abound in or (10 -

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[11] The bedrocks of Hawaiian volcanos are chiefly basalts which are believed to directly overlie the peridotite shell. Assuming that the crustal balance in this region is well held, the mountain root of Mauna Loa (about 4 km above sea level) must reach the depth as great as 48.3 km below the sea bottom. (The calculation was based on the data that the depth of the sea around the Hawaii Islands is 4.5 km, the thickness of the olivine basalt layer is 5 km [according to Powers, 1955, p. 97, and Poldervaart, 1955, p. 124] and the specific gravity of the peridotite is 3.6). The hypocentral depth of volcanic earthquakes (prior to effusion of lavas) on Hawaii Islands ranges between 48 km and 56 km (Powers, 1955, p. 91) which coincide fairly well with the said result of calculation. The hanging rock body, about 50 km thick, may contain in its interior a gabbro-diorite resulted from an olivine basalt magma (zenoliths of gabbro have been reported), and hence it is probable that the recent magma that comes through such rock is provided with an opportunity to assimilate the plutonic rocks.

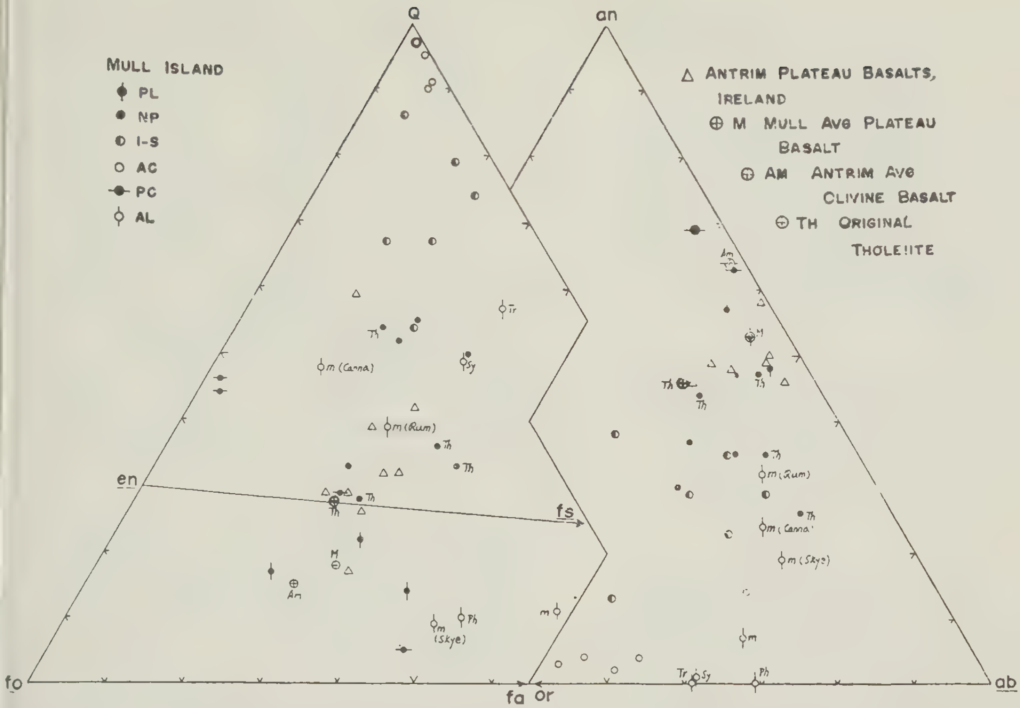

FIGURE 3. Mull Island volcanics and Antrim plateau basalts. Abbrev.-PL, Plateau Magma-Type; NP, Non-Porphyritic Central Magma-Type; I-S, Intermediate to Subacid Magma-Type; AC, Acid Magma-Type; PC, Porphyritic Central Magma-Type; AL, Alkaline Magma-Series; Th, tholeiite; m, mugearite; SY, syenite; Tr, trachyte; Ph, phonolite.

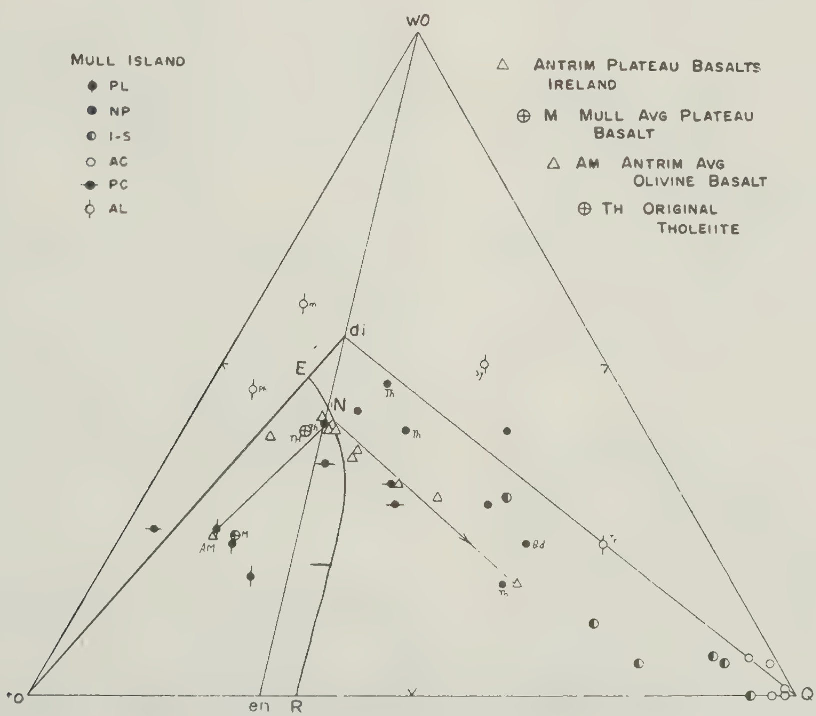

FIGURE 4. Mull Island volcanics and Antrim plateau basalts. Abbrev. refer to those given for Fig.3

16 percent),[12] b) Q-fo-fa variations suggest the Mull Island type rather than the Hawaii type.

Thus, basalts of the Tertiary Hebridean-Irish Region is different from Hawaiian basalts. The difference may be expressed, though not with complete satisfaction extent, by the following terms: 1) Basic tholeiitic series (Mauna Loa and Kilauea), 2) Acid tholeiitic series (Antrim tholeiitic basalts). The basalts of Mull Island can be named, if necessary, "alkali-acid tholeiitic series."

Which of these tholeiitic series represents the normal evolution cannot be determined before the basalts of many other districts are examined by identical method, along with the appropriate petrological considerations.

BASIC THOLEIITIC SERIES OF CENTRAL AMERICA

Occurrence of basalts of basic tholeiitic series is not restricted to areas which lack the sial shell, like Hawaii. Quaternary lavas belonging to the same series as the Mauna Loa-Kilauea lavas have been reported from Mexico, Nicaragua (including 1923 lavas), Panama, Martinique and St. Vincent (Burri and Sonder, 1936) (refer to figs. 1, 2). Of the thirteen data in the diagrams, ten belong to the basic tholeiitic series, two to the acid tholeiitic series, and one is abnormal (contaminated) type. As a whole, they are considered to belong to the basic tholeiitic series.

This recognition, however, concerns only the olivine-pyroxene relations. In other features, the Mauna Loa - Kilauea lavas are not always analogous to the Quaternary lavas of Central America. Normative feldspar composition, for example of many rocks of the former group is more than 10 percent or, whereas in the majority of the latter it is less than 10 percent (5 to 8 percent in most cases). An especially noticeable difference is found in the alkali-TiO_2 relation [13] (fig. 5).

In summary, the following can be said. The

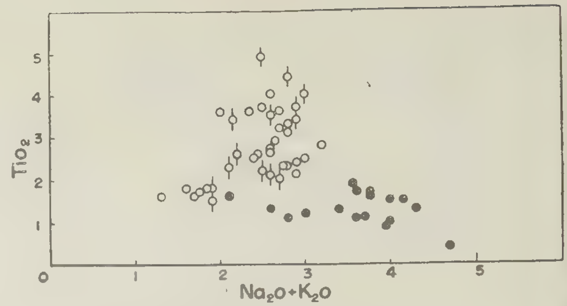

FIGURE 5. Diagram showing a decided difference in the Na_2O+K_2O and TiO_2 relation between Mauna Loa-Kilauea basalts and the Quaternary lavas of Central America (Mexico, Nicaragua, Panama, Martinique, and St. Vincent).

two groups of lavas resulted from different magmas are analogous in the view of the olivine-pyroxene relations, and reversely, even if certain two groups of rocks belong to the tholeiitic series, their magmatic evolution may not have been identical.

BASALTS OF THE CIRCUM-JAPAN SEA ALKALINE PROVINCE

Basalts occurring in the Cenozoic alkaline rock provinces surrounding the Sea of Japan are classified into three types as described below.

1) Alkali olivine basalts: Many of them are trachybasaltic. In the wo-fo-Q diagram (fig. 7) they are plotted in the zone along the di-fo line.[14] This zone can be distinguished from the tholeiitic basalt zone (central part of the olivine zone), and the course of evolution indicates the simultaneous crystallization of olivine and pyroxene.

These basalts belong to the alkali rock series, and their evolution course in the Q-fo-fa diagram (fig. 6) is represented by a clockwise trend (pyroxene type differentiation, Tomita, 1951). In this type, evolution advanced to such an extent that the area around the olivine-pyroxene zone became trachyandesitic. That the evolution of alkali volcanic rocks is characterized by long-term crystallization of olivine (as compared with that of feldspars) was

[12] Original tholeiite (Tröger, 1935) also abounds in or (normative feldspar, or:ab:an = 17:37:46). Modal minerals are zonal plagioclase (An 65 - 50) 52, augite 18, olivine 7, iron ore + apatite 2, interstitial filling, consisting of plagioclase, augite and iron ore ± glass basis, is 21 percent. The general belief that tholeiitic basalts are poor in alkali is not correct.

[13] Basalts of the so-called alkaline rock provinces characteristically abound in TiO_2, whether or not they are tholeiitic or non-tholeiitic (alkalic). This nature is one of the important problems of future study of basalts.

[14] For determination of the area of the parental alkali basalt magma, "normal alkali basalt" (Nockolds, 1954), "Pacific gross average," "Atlantic gross average" (Green and Poldervaart, 1955) and "Carboniferous Scottish olivine basalt" (Tomkeieff, 1937) were plotted in Figure 7. In this area are shown the Dōgo parental magma and the Gembudo basalt.

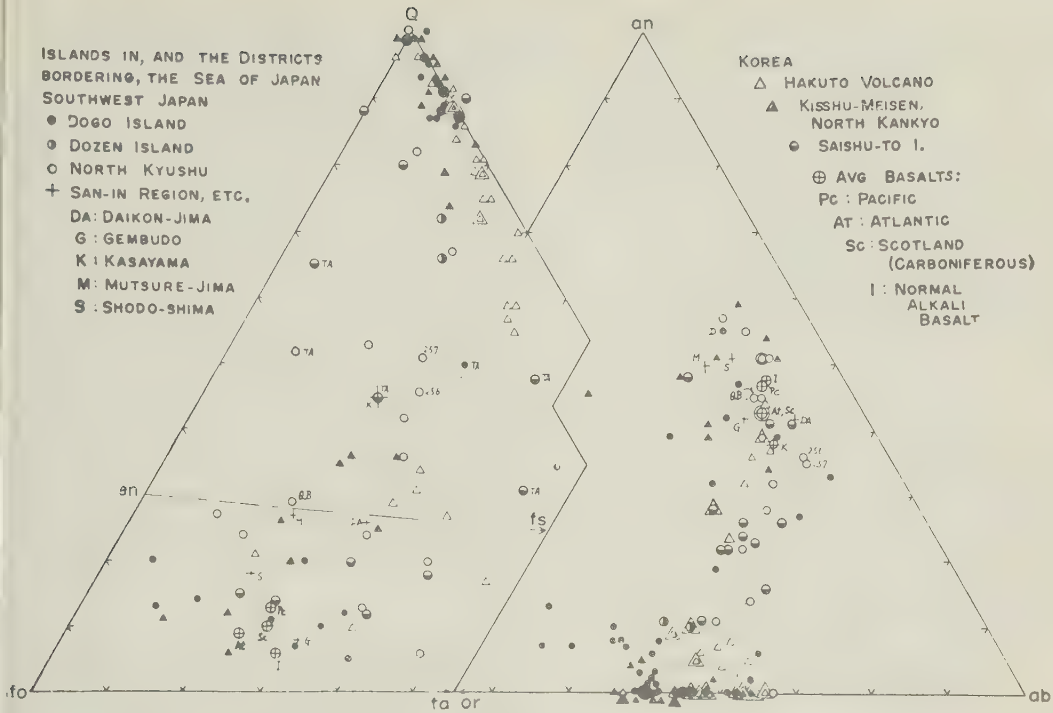

FIGURE 6. Volcanic rocks of the Cenozoic alkaline suite of the Circum-Japan Sea petrographic province. Abbrev.-TA, trachyandesite; QB, quartz basalt from Ogawa-jima.

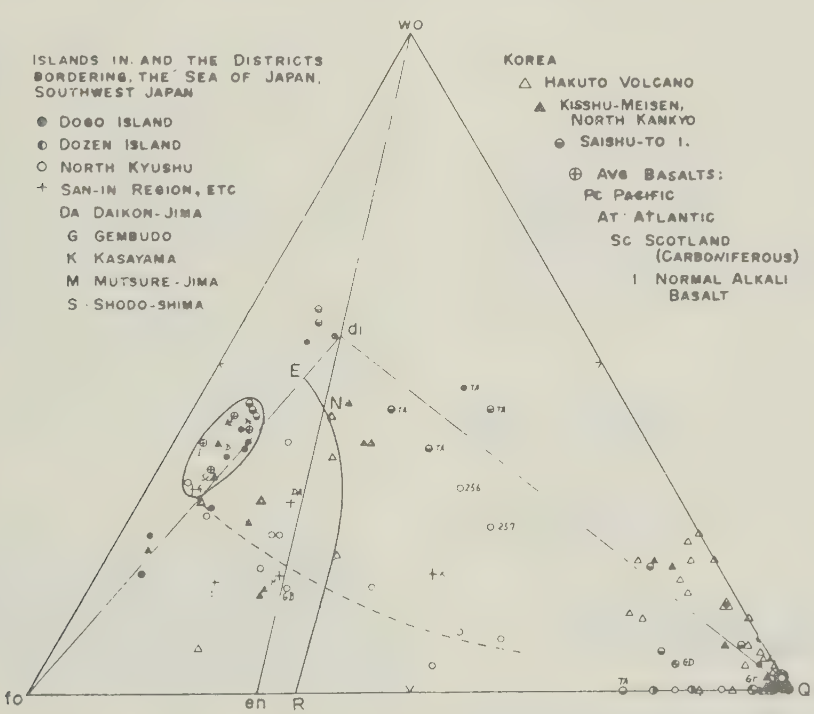

FIGURE 7. Volcanic rocks of the Cenozoic alkaline suite of the Circum-Japan Sea petrographic province. Abbrev.-TA, trachyandesite; QB, quartz basalt from Ogawa-jima; GD, Daly's average granodiorite; Gr, Daly's average granite.

pointed out by the writer (Tomita, 1932, p. 682). This characteristic is shown in the diagram at the right in Figure 6.

2) Tholeiitic olivine basalts and basalts: These rocks occur, in association with alkali basalts, in the vicinity of Paektu-san and other districts of North Korea, in the San'in region and northern Kyushu. Their abundance ratio to alkali basalts is not known, but as far as the field observations go they are less than alkali basalts. Olivine does not necessarily have a pyroxene reaction rim. (Only after chemical analysis they are known to be tholeiitic; fig. 7).

3) Normal basalts in alkaline rock provinces: Basalts in northern Kyushu, North Korea, and Paektu-san, include alkali basalts, tholeiitic basalts and some abnormal basalts whose nature differs markedly from any other kinds of basalt. These abnormal basalts have been considered as tholeiitic basalts until very recent. They are interesting and important in view of the genesis of basalts, so the writer discusses them in the separate section.

ABNORMAL BASALTS OF NORTHERN KYUSHU

Basalts of northern Kyushu are roughly divided into two kinds; 1) those which belong to the alkaline rock series, and 2) those do not. The latter group is unexpectedly predominant and includes the kinds having abnormal chemical compositions.

In Figure 7, the quartz basalts[15] of the San'in region (Da from Daikon-jima;[16] K from Kasayama) occur on the straight line connecting alkali olivine basalt and granodiorite (GD) - granite (Gr). Distributed sporadically in the area beneath the quartz basalts are the abnormal basalts in question and the tholeiitic olivine basalts.[17, 18] They occur along the dashed curve of the figure. This curve starts from a point (No. 260) within the area of alkali basaltic parental magma and extends towards granodiorite (GD) and granite (Gr), although whether or not it represents the course of evolution has not been determined as yet.[19]

Such basalts as mentioned above, having abnormal chemical compositions, are not known among the rocks of Mauna Loa - Kilauea region and Mull - Antrim region, and are evidently different from the generally called tholeiitic basalts in foreign countries. Tilley (1950, p. 39) mentioned the fact that "tholeiitic series" occurs in Hawaii where the sial shell is absent, and he confuted the writer's hypothesis (1935, p. 300) which attributed the origin of the oversaturated basalts in northern Kyushu and San'in to the assimilation of the sial shell by alkali olivine basaltic magma. Tilley's argument, however, becomes meaningless when we realize that the basalts of northern Kyushu and San'in entirely differ from the basalts of foreign countries. Also, there is no counterevidence by which revision of the writer's hypothesis is necessitated.

The interesting controversy on the origin of basalts has led to the fact that the basalts discussed were originally of different kinds. Looking into the matter, the discussion was caused by the writer's immature knowledge by which the oversaturated basalts of northern Kyushu and San'in were mistaken for "tholeiitic basalts," an error the writer regrets. Through such experience as this, we learn that petrologic research by modes only is liable for errors.[20]

That the majority of the basalts of northern Kyushu differ from the "tholeiitic basalts" of Mauna Loa - Kilauea and Mull - Antrim districts has been already mentioned. The writer has learned, by examining $\underline{wo}$-$\underline{fo}$-$\underline{Q}$ diagrams, that the lavas of Ōmuro Volcano, Izu Peninsula, to be similar to the northern Kyushu basalts (fig. 8). According to Kuno (1954) the Ōmuro lavas are basalt and dacite containing granitic xenoliths and quartz xenocrysts, and are the product of contamination of the parental magma of this volcano and granitic rocks.

Thus, as far as the $\underline{wo}$-$\underline{fo}$-$\underline{Q}$ diagrams are

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[15] Quartz in quartz basalts is xenocryst. Hence, strictly speaking, the rocks should be called quartz-xenocryst basalts.

[16] Result of analysis of samples excluding quartz xenocrysts.

[17] When compared with the tholeiitic olivine basalts of foreign countries (fig. 8) which are thought parental magmas, they contain less $\underline{wo}$ and more $\underline{Q}$.

[18] Analytical data are according to Iwasaki, Katsura and Fukutomi (1954), Kobayashi, Imai and Matsui (1955), and Kobayashi, Imai and Matsui (1956). The present writer has lately obtained twelve new data which will be reported in the near future.

[19] For the following reasons: in the $\underline{wo}$-$\underline{fo}$-$\underline{Q}$ diagram the distribution of the respective points seems to prove that evolution took place, whereas in the $\underline{an}$-$\underline{ab}$-$\underline{or}$ diagram the corresponding points are irregularly distributed; influence of assimilation of granodiorite or granite ought to be taken into account perhaps. This problem is difficult to solve in spite of many occurrences of xenolithic granite.

[20] A similar case is discussed in the section on the basalts of Indo-China.

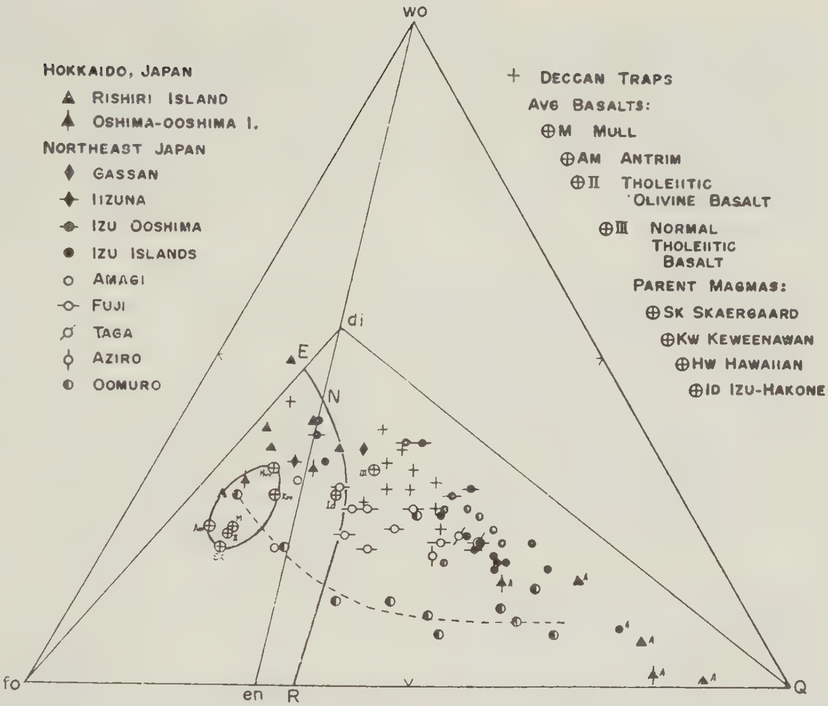

FIGURE 8. Basaltic rocks and some andesites from the volcanoes of Hokkaido and Northeast Japan together with the Deccan Traps. Abbrev.-A, andesite.

concerned, a close resemblance is recognized between the northern Kyushu basalts and the Ōmuro lavas. Had Kuno's genetic theory been correct, the abnormal chemical composition of the basalts in northern Kyushu would perhaps be attributed to assimilation and contamination of granitic rocks. However, in other kind of diagram, for instance in the MgO-($FeO+Fe_2O_3$)-(Na_2O+K_2O) diagram[21] (fig. 9), the rocks of these two districts bear no similarity. This will be explained below.

In Figure 9, the following facts are noticed. 1) The differentiation course of the volcanic rocks in the southern margin of the Circum-Japan Sea alkaline province (Oki Islands, San'in district, Cheju-do, and northern Kyushu) resembles that of the Mull volcanics (Kuno, 1954, fig. 71); 2) Probably contaminated rocks such as the Kasayama quartz basalt (K), the Ogawa-jima quartz basalt (QB) and the Mutsurejima mica basalt (M) abound in $FeO+Fe_2O_3$ and are slightly rich in alkali; 3) Uncontaminated rocks such as the Gembudō basalt (G) are poor in $FeO+Fe_2O_3$ and rich in alkali; 4) The majority of the abnormal basalts of northern Kyushu are rich in $FeO+Fe_2O_3$ and Na_2O+K_2O.

Such chemical characteristics as mentioned above are not found in the Ōmuro lavas (Kuno, 1954, fig. 6). Moreover, it deserves attention that the northern Kyushu basalts do not belong to hypersthene rock series. Hence, assuming that the formation of the northern Kyushu basalts, especially those abnormal basalts, is attributable to assimilation and contamination of granitic rocks, the wo-fo-Q diagram which represents the phenomenon is thought to be better than the MgO-($FeO+Fe_2O_3$)-(N_2O+K_2O) diagram. It goes without saying that the former shows the effect of Al_2O_3 whereas the latter does not. As the effect of Al_2O_3 is indispensable in assimilation of sial substances, it is natural that the wo-fo-Q diagram has advantages over other diagrams. Thus, in this diagram the rock types originated in migmas are found in the region where wo is poor and Q is rich, far apart from the normal evolution course of the parental magma.

BASALTS OF VOLCANIC ZONES OF JAPANESE ISLANDS

Of the basalts occurring in the volcanic zones of the Japanese Islands, those of northeastern Japan and Hokkaido are dealt with in this paper, for the reason that these rocks have not been properly understood. The date of

[21] Fe_2O_3 was converted into FeO for calculation.

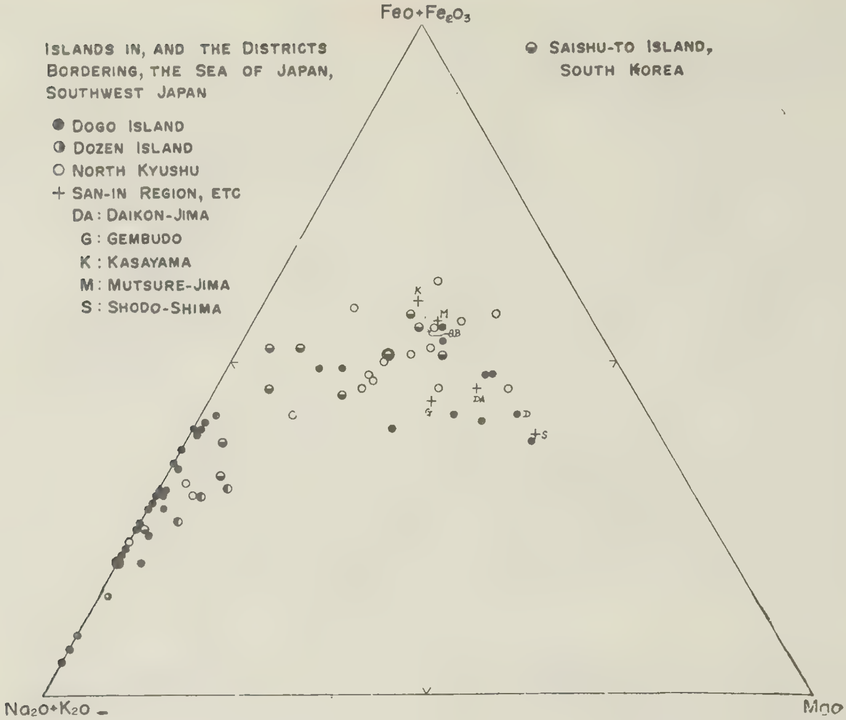

FIGURE 9. Volcanic rocks from islands in, and the districts bordering, the Sea of Japan, Southwest Japan, and Saishu-to Island, South Korea, in the Circum-Jâpan Sea petrographic province. Abbrev.- QB, quartz basalt from Ogawa-jima.

chemical analysis treated here[22] may not include all information available at present, but the writer would be content if the purport of this study is comprehended by the reader.

From the wo-fo-Q diagram in Figure 8 the following facts are known: 1) The basalts of Rishiri Island have been derived from a tholeiitic olivine basalt magma similar to alkali olivine basalt magma. Although the main course of evolution is that of the tholeiite series it also shows an alkali series differentiation. 2) The basalts of Oshima-Ooshima are tholeiitic olivine basalts and their evolution belongs to the "acid tholeiitic series." Similar characters are noticed in the basalts of the inner, or Japan Sea side, volcanic zones of northeastern Japan. 3) The basalts of Izu-Ooshima and other islands of Izu are thought to belong to the "acid tholeiitic series." The nature of their parental magma has not been determined as yet, but at least it does not seem to be identical with the Izu-Hakone parental magma reported by Kuno. 4) The basalts of Izu Peninsula and Fuji Volcano may belong to the "basic tholeiitic series," only somewhat poor in wo. Kuno's Izu-Hakone parental magma is the source of these basalts only. However, as Figure 8 indicates, this parental magma has a chemical composition characteristically different from any of the parental magmas of the well known tholeiitic olivine basalts of the world. Had the Izu-Hakone parental magma been just as Kuno maintains, the writer believes that the magma should be treated as the third parental magma from the world-wide viewpoint, and that the genetical consideration of the magma must be made independent of the genetical problems on other kinds of parental magma, such as alkali olivine basalt magma and tholeiitic olivine basalt magma.[23]

Summarizing the above, two geologically important facts are known: 1) The basalts in the volcanic regions of Izu Islands and Hokkaido are allied to the tholeiitic olivine basalt magma

[22] Analytical data cited from: Isshiki (1955), Katsui (1953), Kuno (1936), Kuno (1950, 1953, 1954), Morimoto et al (1955), Tsuya (1937), Tsuya and Morimoto (1951).

[23] The formation of alkali olivine basalt magma and tholeiitic olivine basalt magma is considered to be related to the selective refusion of the peridotite shell advocated by Bowen (1928, p. 315-325). The writer thinks that the Izu-Hakone parental magma may be a refusion product of underground gabbro.

of the acid tholeiitic series, whereas the basalts of Izu Peninsula and Fuji Volcano belong to the rock type having less wo (although they include the rock types similar to basic tholeiitic series the evolution course entirely differs from the latter). 2) No basalts allied to those of northern Kyushu are found in Izu Islands, in Hokkaido, or in the inner volcanic zones of northeastern Japan.

CENOZOIC BASALTS OF INDO-CHINA

The southeastern part of Indo-China (southern Loas, southern Viet Nam and Cambodia) is noted for the Miocene to Recent basalt plateaus and puys which are extensively distributed.[24] Few reports have been made on the basaltic rocks of this region except the paper by Lacroix (1933, p. 123-141), and the rocks have been seldom referred to by students of basalts. Why these rocks are discussed here from the viewpoint of modern petrology is explained below.

1) The geologic position of the Indo-Chinese basalt region -- its location as the inland core against the Java-Sumatra andesite region -- corresponds to the North Korean-Manchurian basalt region which occurs as an inland core in contrast to the Japanese Islands andesite region. 2) The rocks are olivine basalt rich in K_2O, and in this respect the resemble the olivine basalts of Manchuria. 3) These alkali olivine basalts are associated with tholeiitic basalts, and this furnishes information useful for the study of genetic relationship between the two groups of rocks.

The basalts in question include the following kinds; a) alkali olivine basalt, b) tholeiitic basalt (olivine basalt - bronzite basalt), c) limburgite, d) zeolite basalt. Of them the first two rocks are discussed in this paper (figs. 10, 11).

Alkali olivine basalt: This is characterized by normal olivine[25] and purple augite. It shows a marked normative feldspar composition and is rich in or, but groundmass biotite is nonexistent. In most cases or is assumably contained in the groundmass glass, although there is a rock type having potash-feldspar rim around plagioclase. The occurrence of nonporphyritic rock type (Nos. 126, 132, 133) is interesting in view of the study of magmatic problems.

Tholeiitic basalt: This is divided into the following rock types which are plotted in Figure 10 and Figure 11. (i) Olivine dolerite containing olivine that was somewhat affected by reaction,[26] (ii) porphyritic oversaturated basalt (No. 120) both containing olivine that underwent marked reaction,[26] (iii) olivineless dolerite, (iv) bronzite basalt (including doleritic type retaining reaction olivine, glassy vitreous type (No. 118) and andesitic dolerite). Of these, the doleritic type is said to contain pigeonite.

When the rock types of the tholeiitic basalt are examined chiefly on the basis of the olivine-pyroxene relations, they are known to have undergone evolution and differentiation like those of Tilley's "tholeiitic series" (fig. 10-a). On the other hand, in the normative feldspar diagram (fig. 10-b), the evolution of the feldspar composition does not necessarily correspond to the evolution of mafic minerals, but is rather in a reverse course.[27] In short, the more the rocks abound in Q their plagioclase is more calcic. This unusual fact presents a new problem for the study of basalt genesis.

The above-mentioned characteristic is related to foreign materials in oversaturated basalts. In the porphyritic oversaturated basalt and nonporphyritic oversaturated basalt containing olivine that underwent marked reaction (rock type ii) are found xenoliths of crystalline schist and xenocrysts of andalusite,[28] and bronzite basalt (rock type iv) contains xenoliths of gneissose rocks and nodules of sillimanite.

On the basis of such foreign inclusions the following genetic hypothesis becomes possible: 1) The parental magma is assumed to be an

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24 The following basalts are known as the product of Recent activity: 1) Puys of northern Viet Nam; 2) Ile de Cendres (29 km south of Paulo Cécir der Mer Island off the southeastern coast of Indo-China). This is a shortlived volcanic island (formed a scoria cone) resulted from the submarine eruption of 1923 March. The constituent rock is olivine basalt containing normative ne.

25 Some have no reaction rim, and some are not fused. Lacroix called such olivine "olivine essentiallement normale."

26 According to Lacroix, "olivine partiellement reactionnelle" and "olivine reactionnelle" respectively.

27 Like the case of norm, a reverse tendency is noticed in mode also; that is, feldspar in olivine dolerite (i) is zonal andesine-oligoclase, while it is labradorite in bronzite basalt (iv).

28 Andalusite shows a fused appearance and is surrounded by beautiful aggregates of plagioclase and spinel (Lacroix, 1933, pl. V).

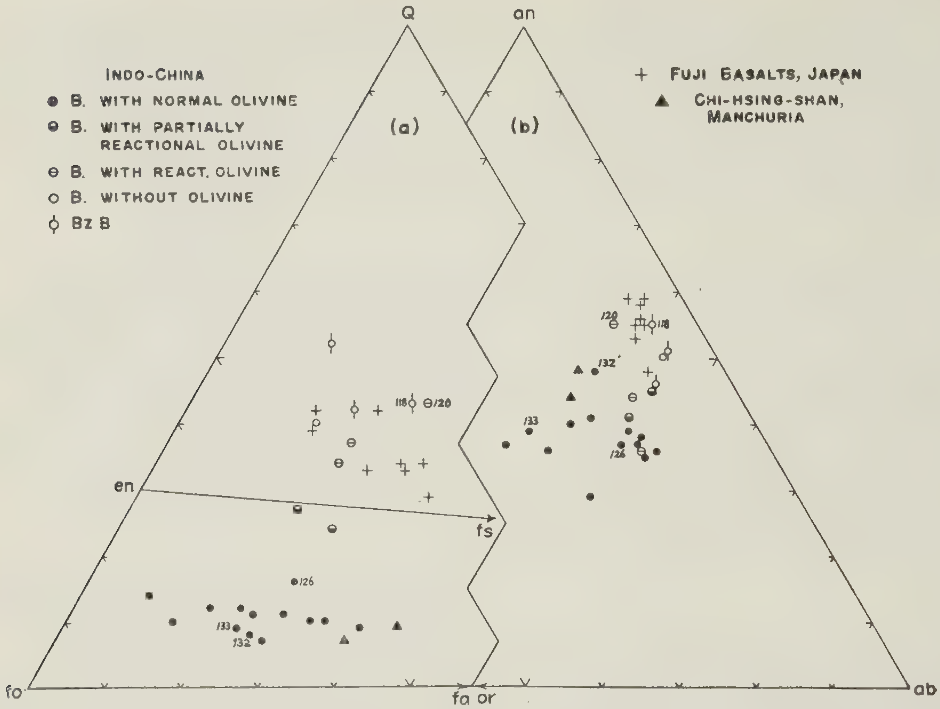

FIGURE 10. Cenozoic basalts and dolerites of Indo-China, basalts from the Fuji Volcano, Japan, and non-porphyritic basalts from the Chi-hsing-shan Volcano, Manchuria. Notes.-Nos. 118, 126, 132, 133: aphanites; No. 120: glassy rock.

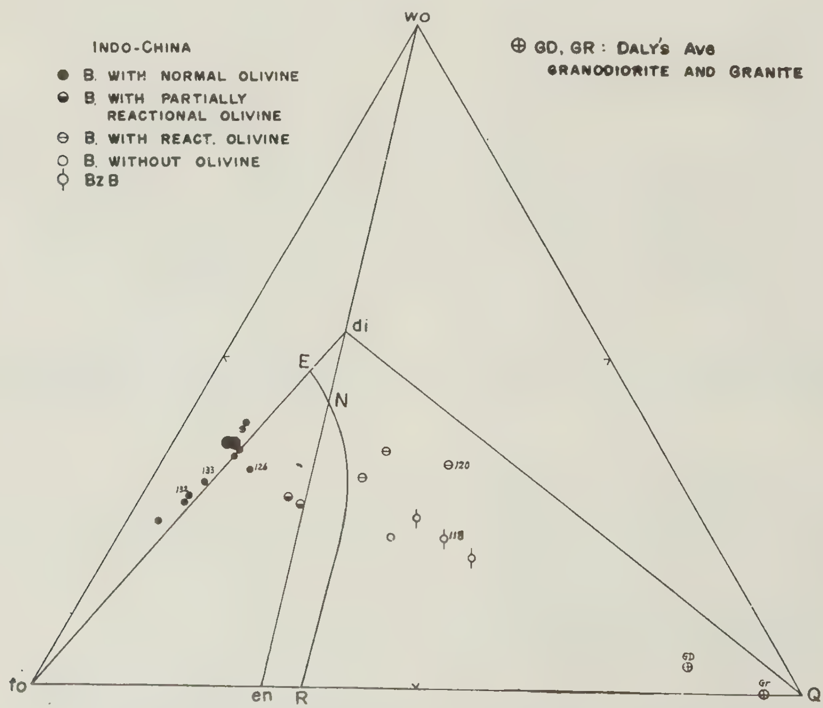

FIGURE 11. Cenozoic basalts and dolerites of Indo-China. Notes.-Nos. 118, 126, 132, 133: aphanites; No. 120: glassy rock.

alkali olivine basalt magma.[29] 2) Due to reactional assimilation of alumina-rich foreign inclusions like crystalline schist, molecular re-adjustment takes place in the magma on account of addition of Al_2O_3 and SiO_2, and $MgSiO_3$ + $CaAl_2Si_2O_8$ molecules are produced.[30] 3) As the molecular re-adjustment progresses along with reactive assimilation, rhombic pyroxene molecule ($MgSiO_3$) and anorthite molecule ($CaAl_2Si_2O_8$) show a parallel increase. 4) With advance of crystallization, the abundance ratio of mineral phase may finally reach a stage markedly different from the parental magma, and in such a case the effect of reactive assimilation of foreign inclusions may be manifested in the chemical compositions of the resultant rocks. Thus, there would be some cases where the abnormal chemical composition serves as evidence of assimilation.

The above hypothesis will be examined on the wo-fo-Q diagram (fig. 11). The figure indicates the following facts: 1) There is a series ranging from alkali olivine basalt to bronzite basalt, passing through tholeiitic olivine basalt, and in this series Q increases with decreasing wo. 2) Oversaturated basalt[31] containing reaction olivine occupies the area somewhat rich in wo, apart from the above-mentioned series.[32] 3) The Fuji basalts plotted in the figure for comparison are known to scatter in the area of the oversaturated basalts.[33] This decrease in wo and increase in Q may represent increase Al_2O_3 and SiO_2, judging from the method of normative calculation.

The result of study of the Indo-Chinese basalts can be summarized as follows: 1) When alkali olivine basalt magma affects crystalline schists by reactive assimilation, wo-less tholeiitic rocks form. 2) The rocks having abnormal chemical compositions, like the wo-less tholeiitic rocks, are the result of complex effects of contamination and the initial chemical composition. 3) Volcanic rock series established on the basis of modal olivine-pyroxene relations does not necessarily represent the evolution course of the primary magma by fractional crystallization. 4) It cannot be asserted that the Fuji basalts are a migmatic product before further investigations are made.

THOLEIITIC BASALTS

Since olivine basalts were divided into "tholeiitic" and non-tholeiitic"[34] (Tilley, 1950, p. 41), the ambiguity in calling them merely "olivine basalts" has been removed. On the other hand, tholeiitic basalts have been dealt with still in a simple way, which causes confusion in discussing magmatic evolution and related problems.

"Tholeiitic basalts" include various rock types of different origin. Figure 12 shows the volcanic rocks[35] of the Eastern Asiatic Cenozoic alkaline region as well as those from the foreign localities treated in this paper; in the figure the distribution area of tholeiitic basalts (including tholeiitic olivine basalts) is bounded by a dashed line. The basalts are divided into contaminated type and uncontaminated type.[36] The figure reveals the following facts: 1) The distribution area of tholeiitic basalts is markedly

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[29] This parental magma supposedly has a composition similar to No. 132 (fig. 10). In the composition of normative feldspar, the near-aphanites of Chi-hsing Volcano, Manchuria, are similar to this magma. Such or-rich parental magma seems to occur commonly in the inner part of the continent. Whether the magma is primary or derivative is a problem which should be discussed along with parental magmas of other districts. The discussion is so diversified and lengthy that it is omitted here.

[30] Possibility of molecular re-adjustment has been discussed in detail by Bowen (1928, p. 208).

[31] This refers to the afore-mentioned "porphyritic oversaturated basalt and non-porphyritic oversaturated basalt containing olivine that underwent marked reaction" (rock type ii). The reactive olivine is supposedly relict crystals. The non-porphyritic oversaturated basalt (No. 120) is thought to represent a liquid phase of porphyritic oversaturated basalt (refer to fig. 10 also).

[32] The reason of its being apart from the series is probably because the groundmass augite is common augite. The rock type having diopsidic augite is plotted near di, apex of di-fo-Q. It must be noted that the rocks in question are porphyritic but contain no augite phenocrysts.

[33] With regard to the resemblance between Fuji basalts and oversaturated basalts, refer to Figure 10.

[34] In actuality, however, such discrimination is very difficult sometimes. For example, the basalt region of northern Kyushu yields both types of olivine basalts, containing normal olivine. The two types can be distinguished only after chemical analysis is made.

[35] Limburgite, analcite basalt and feldspathoid rocks are excluded.

[36] Research on igneous rocks by means of Q-fo-fa diagrams has remarkably advanced these days. Figure 12 is one of such diagrams. The usefulness of this way of representation will be discussed in another paper by the writer.

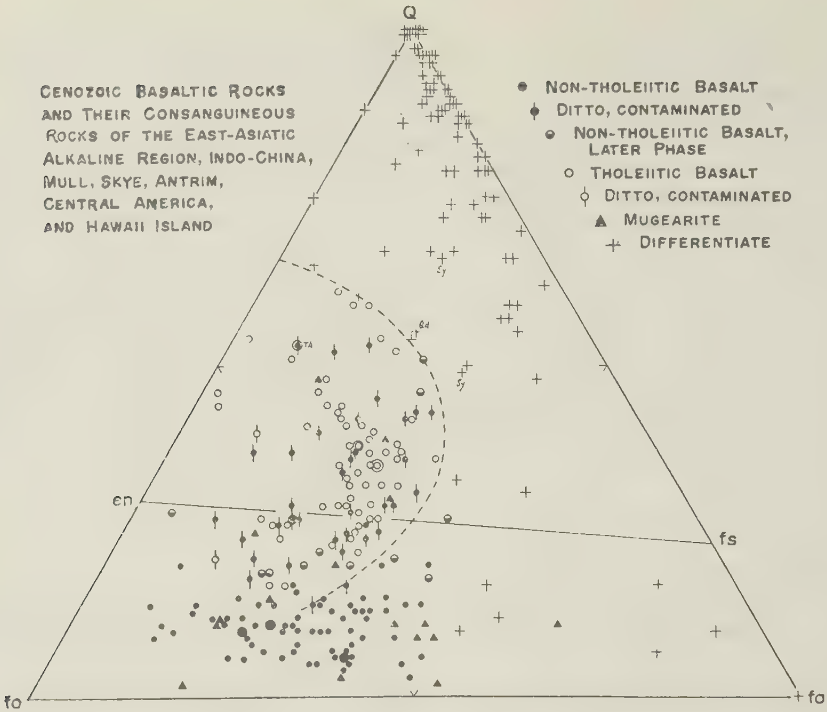

FIGURE 12. Cenozoic basaltic rocks and their consanguineous rocks of the East-Asiatic alkaline region, Indo-China, Mull, Skye, Antrim, Central America, and Hawaii Island. The points within the dotted curve are the basaltic rocks of tholeiitic rock-series. Abbrev.-TA, trachyandesite; Qd, quartz dolerite; Sy, alkali-syenite.

wide (suggesting their varying chemical compositions). 2) The area is limited in the side where Mg is rich. 3) Alkaline volcanic rock series occurs in the Fe-rich side. As far as the Q-fo-fa relation is concerned, the tholeiitic basalts resulted from contamination of alkali basalts magma are hardly distinguishable from the tholeiitic basalt formed by fractional crystallization of tholeiitic basalt magma (which suggests that tholeiitic basalts are derived from magmas of corresponding chemical compositions, irrespective of the origin of magma).

CONCLUSIONS

Chemical compositions of basalts were studied by the diagrams of an-ab-or, Q-fo-fa (Tomita, 1951) and wo-fo-Q (newly proposed). Through these diagrams the natural crystallization course, compared with the experimental dat', is well understood; hence, these diagrams are much more useful in the study of phase petrology than other ways of representation.

The following facts became known by the above-mentioned diagrams.

1) In the newly proposed wo-fo-Q diagram, three major series of basalts -- alkaline rock series, tholeiitic rock series, and contaminated rock series -- are clearly discerned. In the alkaline rock series, magmatic evolution advances in the direction where olivine and pyroxene are concurrently crystallized, whereas in the basalts of tholeiitic rock series the crystallization course is such that olivine and pyroxene are in a reactive relation. The crystallization course of basalts of contaminated rock series differs distinctly from either of the above two.

2) The Mauna Loa - Kilauea basalts and the Mull - Antrim basalts both belong to the tholeiitic rock series but differ in the evolutional course, the former is tentatively grouped as basic tholeiitic series and the latter as acid tholeiitic series. The cause of such difference requires further study.

3) Basalts of volcanic islands such as Rishiri Island, Oshima-Ooshima of Hokkaido, and Izu Islands belong to the acid tholeiitic rock series. Basalts of Izu Peninsula and Fuji Volcano are similar to those of basic tholeiitic rock series of a later stage.

4) The "parental magma of Izu-Hakone district" (Kuno) shows a chemical composition entirely different from typical tholeiitic basalt magmas. This "parental magma" and related problems must be investigated in detail. The

present paper did not deal with them because they are rather local features.

5) As an example of tholeiitic basalts resulted from contamination of alkali olivine basalt magma, the Indo-Chinese Cenozoic basalts were discussed. Their chemical compositions are greatly different from other basalts of tholeiitic series such as Mauna Loa - Kilauea and Mull - Antrim basalts.

6) Some of the "tholeiitic basalts" of northern Kyushu differ from tholeiitic basalts of foreign countries. They are probably contaminated volcanic rocks, but the present paper treated them as "abnormal basalts" because the study is still under way.

7) In studying the genesis of igneous rocks no decisive conclusion should be drawn out of only one chemical composition diagram. Therefore, the reader is requested to understand that in the present paper the whole essential nature of basalts was not dealt with, rather emphasis was placed on the olivine-pyroxene relation.

As mentioned in the Introduction, this paper does not set forth the whole of the writer's view. The writer intends to cover in later papers problems other than discussed here. He believes that for reaching the truth of the nature of basaltic rocks, phase petrological viewpoints alone do not suffice. Many of the things mentioned in this paper are merely suggestive, and a need for advanced research and new ideas, is keenly felt.

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STRUCTURAL CONTROL OF IGNEOUS INTRUSION INTO COAL-BEARING FORMATIONS AND THEIR THERMAL METAMORPHIC ACTION[1]

by

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• translated by Reiko Fusejima •

ABSTRACT

Many sills and dikes intruded the southern half of the Chikuhō Coal Field in Kyushu. The mechanism of intrusion, petrology of the igneous rock, and thermal metamorphism of the coal were studied in the Ōminé and Shimoyamada mines. Sills selectively intrude only thick seams of coking coal. Two modes of sill intrusion are apparent: 1) flows of fluid magma freely following the plane of bedding before solidification and, 2) forced intrusions of solidified andesite which pulverized the coal in the seam as it progressed. The sills originated from magma rising along steeply dipping tension cracks caused by pressure of the magma chamber, and now filled with dike rock. Areal folding and faulting preceded the intrusion of sills and dikes. The igneous rock is two-pyroxene andesite containing saponite pseudomorphs of olivine. Thermal metamorphism has resulted in variations of coal ranging from semi-anthracite to natural coke. --M. Russell.

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INTRODUCTION

In the southern region of the Chikuhō coal field that extends over Tagawa-gun and Kaho-gun of Fukuoka Prefecture, the Paleogene coal-bearing formation is commonly intruded by igneous rocks. As a result thermal metamorphism altered much of the coal to senseki (decrepitative cinder coal) and hakuen[3] (low grade cinder coal). Aiming at clarification of the mechanism of igneous intrusion and the thermal metamorphism of coal seams, the writer has been investigating the Ōminé and the Mineji collieries in the Ōminé mine of the Furukawa Mining Company. This paper summarizes the results of a study which is still underway. A more detailed report will appear later.

GEOLOGIC OUTLINE

The Ōminé mine occupies the southern half of the Tagawa district, including the towns of Kawasaki and Soeda. Mt. Hiko towers to the south. The Paleogene formation terminates in the vicinity of Masuda south of Soeda-machi, and the Kamisoeda colliery is the only coal producer in the area south of the Ōminé mine. The Paleogene formation forms an asymmetric synclinal structure with a roughly N-S axis. The general strike is NNW-SSE on the west limb where the dip is about 10° NE. The east limb abuts bed rock (consisting of granite and Sangun-type metamorphic rocks) with a normal fault that runs in the direction of the synclinal axis and has a great throw. The dip is 40° to 60° NW, locally vertical or even reversed. The synclinal axis is locally almost horizontal but on the whole it gently plunges to the north. As a result, lower beds are exposed gradually toward the south.

The Paleogene formation of the report area comprises the Nōgata group, the lowermost member of the Chikuhō coal field, and the Ideyama formation, the lowermost complex of the Ōtsuji group. The Ideyama formation occurs only in the northeast margin of the area. Table 1 shows the thickness of the Paleogene beds in the Ōminé and Mineji collieries.

OUTLINE OF COAL SEAMS

The coal seams of the Ōminé and the Mineji collieries are seventeen in number and all along to the Nōgata group. They are listed in Table 2 in descending order.

Sills intrude all beds of the Nōgata group, occurring mostly in coal seams and rarely in sedimentary rocks. Sill intrusion in coal seams however, is not uniform. Sills are generally abundant in lower seams, but while they are especially numerous in one seam there are few or none in another seam. It is also commonly observed that one of the adjacent two seams with a short interval is selectively intruded by sills. In the Ōminé and the Mineji collieries the major coal seams abound in sills. This signifies that seams having a larger thickness and less part-

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[1]Translated from the Japanese: in Jubilee Publication in Commemoration of Professor Jun Suzuki, M.J.A., Sixtieth Birthday (1956), p. 253-262, 1958.

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[3]Translator's Note: "Senseki" is a miner's term referring to a kind of natural coke. The author in the abstract uses the term "decrepitative cinder coal," so his usage is followed in the translation. "Hakuen", meaning white smoke, has no English equivalent, but it may refer to a cinder coal of low degree of coalification. In this paper it is translated as "low-grade cinder coal."

TABLE 1. Stratigraphic sequence and thickness of beds in the Ōminé district

Group	Formation	Thickness in Ōminé colliery (m)	Thickness in Mineji colliery (m)
Otsuji group	Ideyama formation		
----- Unconformity -----			
Nōgata group	Kamiishi formation	187.74+	
	Takeya formation	205.56	63.99+
	Main coal seams (3 ft, 5 ft)	155.57	122.81
	Ōyake formation	217.61	198.26
-----Unconformity ----			
	Bedrock		

TABLE 2. Coal seams and their characteristics

Formation	Coal seam	Interval (m)	Thickness Seam (m)	Thickness Coal (m)	Coal thickness / Seam thickness	Coking property of unmetamorphosed coal	Igneous intrusion
Kamiishi	Kawara 8-ft		1.95	1.45	0.74	x	x
		112.11					
	Ida 5-ft		0.68	0.21	0.31	x	x
		206.04					
Takeya	•Takeya 5-ft		1.40	0.95	0.68	x	Sills
		12.12					
	•Takeya 3-ft		2.21	1.52	0.69	x	Sills (flaming coal and anthracite)
		6.67					
	•Takeya-Shakunashi		1.36	1.00	0.74	Highly coking	Sills (flaming coal and anthracite)
		18.76					
Main coal seam	New 8-ft		0.83	0.24	0.29	Weakly or slightly coking	No intrusion
		34.24					
	Tagawa 8-ft		2.06	1.64	0.80	Weakly or slightly coking	Sills
		50.00					
	Tagawa 3-ft		5.23	3.55	0.68	Highly coking	Dikes and sills
		2.12					
	Tagawa 4-ft		2.66	1.70	0.64	Not coking or slightly coking	Dikes and sills, but less than above
		93.93					
Ōyake	Ōyake-Shakunashi		0.79	0.25	0.32	x	x
		31.82					
	Ōyake 5-ft		2.58	1.49	0.58	Highly coking	Sills
		2.42					
	Ōyake 3-ft		1.02	0.63	0.62	x	Few sills
		39.39					
	Yoshiya		0.54	0.22	0.41	Weakly coking	x
		15.15					
	•Tenjonashi		1.48	1.20	0.81	Not coking or slightly coking	Sills and dikes
		13.64					
	New 5-ft		0.80	0.33	0.41	x	x
		7.58					
	New 5-ft lower		0.48	0.18	0.38	Weakly coking or not coking	x
		22.12					
	Sunazakai		0.51	0.20	0.24	x	x

• : being worked   x : unknown

ings favor the sill intrusion, especially when the coal is strongly coking, as is exemplified by the seams of Takeya-Shakunashi, Tagawa 3-ft and Ōyake 5-ft.

DISTRIBUTION OF IGNEOUS ROCKS

Igneous rocks intruding the Paleogene formation occur as dikes and sills, the latter being predominant. Exposures of dikes are few, but sills are widely exposed together with coal seams on the western hilly land, although they have been entirely transformed into gray clay and are hardly distinguishable from sedimentary rocks.

The age of the igneous intrusion is unknown but fairly recent (Late Tertiary to Pleistocene?) volcanic activity is suggested from the fact that intrusion took place after the completion of folding and faulting of the Chikuhō coal field, and that mode of intrusion is governed by the coking property of coal. The degree of coalification also implies a young age.

Dikes in the Ōminé colliery constitute a radial swarm. Such radial growth of dikes is found in other places also. This suggests that at depth there were centers from which dikes were derived in a radial pattern, and these deep-seated eruptive centers may be connected with each other to present a network of distribution and may have served as volcanic vents for surface eruption.

Dikes are exposed from Ihara to Taigyōji, and the strike is parallel to the synclinal axis, i. e. north-south. This direction coincides also with the direction of the fault that separates the Paleogene formation and the bedrock. Although there is no evidence of igneous intrusion directly into the fault, the north-south orientation seems to have favored the intrusion of dikes. However, exposed dikes are only a small portion of entire dikes, and so the greater portion occurs as subterranean dikes mostly grading into sills in coal seams. Hence, the north-south dikes may signify a structural control whereby the dikes, unable to grade into sills, ascended through the strata up to the ground surface.

The underground dikes are radially distributed having a center at depth near the Tagawa dip, and tranverse the main faults (fault 1 and fault 2,) running NW-SE and throwing on the north). They strike N-S, NNE-SSW or NW-SE. A dike of unknown system, striking NNE-SSW, is found in the western level. Flow of sills seems to have been impeded by the faults, because each block differs in the distribution of sills. The mode of occurrence of dikes and sills confirms that intrusion took place after the tectogenesis.

As has been observed in the underground galleries, the sedimentary rocks constituting the hanging and foot walls show no or slight, if any, displacement. In one instance undulation of both walls perfectly fits, had the dike between the walls been ignored. This suggests that dikes have formed within tension cracks, and that both dikes and cracks may have resulted from pressure and intrusion from magma below.

Theoretically, sills can intrude any beds. Nevertheless, drillhole records have revealed that the magma selectively intruded coal seams. However, intrusions into tuffaceous or sandy shale or alternating tuff and shale are known in the Karatsu-Kishima coal fields. Therefore, the above-mentioned selective intrusion can be attributable to a structural control dependent upon the physical properties of the strata and coal seams.

Because sills are solidified magma, there must be a supply source, and the cracks now represented by dikes should have been the source. However, direct relation between dikes and sills is rarely seen, and some mining geologists insist the two are independent. Such view is significant just the same, because the fact there is little relation between the two is an important point. For dikes to grade into sills there must be areas where resistance to the magma is weaker in the horizontal direction than in the vertical. In other words, it is easier for the magma to intrude the coal seams than to continue ascending, or at least the resistance should be approximately same in both directions. Underground observations lead us to the following inference.

a) When steeply dipping or vertical cracks [T. N. ; dikes?] are intruded into the "coal dikes" which will be mentioned later, disturbance of dikes is slight in sandstone, whereas shortening, bending, disruption or termination of dikes is common where sandstone grades into shale. Disturbance or deflection of cracks due to physical changes of strata is well known in ore veins (Newhouse, 1941), and such can occur in igneous dikes also. Disturbance is likely to become intense where the physical properties greatly differ between the beds above and below. Hence, the transition from dikes into sills is supposedly most marked between the coal seams and the hanging wall (shale and sandstone), and upward extension of dikes should be seen only where gaps occur in the hanging wall.

b) In addition to the above-mentioned conditions, the coking property of coal also governs the igneous intrusion. If the coal is highly coking, it is fused by heat and becomes fluid or plastic. At the same time, a decrease in volume on account of the escape of volatile matter and polymerization of coal molecules would accelerate the flow of magma. An example of such case is actually known (fig. 1).

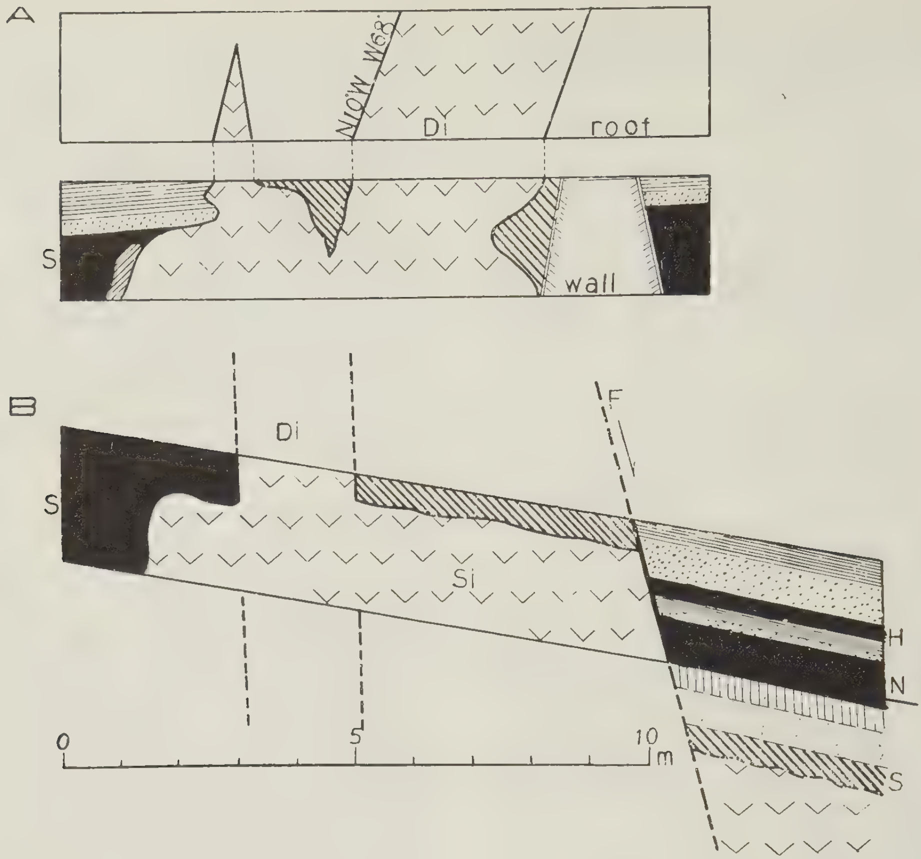

FIGURE 1. Dikes and sills cutting the Tagawa 3-ft seam

A. Ōmine, right 1st level; dike swelling in coal seam and changing its shape in the hanging wall.

B. Ōmine, right 2nd level; dike grading into sill and flowing dipsideward

Di - Dike. Si - Intrusive sill. F - Fault. H - Hassun [8-inch] coal.

N - Nishaku [2-ft] coal. S - Sanjaku [3-ft] coal

Coal. Decrepitative cinder coal Low grade cinder coal

Coaly shale Kaolin-bearing coarse sandstone Sandstone

Shale Igneous rock (andesite of type A)

Friability of coking coal which easily pulverizes under pressure also enhances the capacity for inflow of magma.

MODE OF OCCURRENCE OF SILLS AND DIRECTION FLOW

Igneous rocks occurring as sills in coal seams swell and pinch irregularly, although they occasionally show some uniformity.

The major factors that govern the shape and distribution of sills may be as follows:

a) Direction of flow and fluidity (temperature, viscosity, volatile matter, etc.) of the magma that formed the sills.

b) Geologic structure of the sedimentary rocks (strike, dip, fault, partings, etc.)

c) Movement of the magma.

d) Quality of coal, especially coking property and friability.

Provided with sufficient supply and heat a magma intruding seams of coking coal should be able to permeate through the whole area as far as the geologic structure favors the intru-

tion, until the flow is interrupted by faults or some other agents. The direction of flow is also governed to some extent by gravity. The whole of the Tagawa 3-ft seam, which extends from Ōminé colliery to the Shimarmawari colliery northwest of the former, is pervaded with the igneous rock. This is particularly marked near a dike in the Shimamawari colliery which is thought to be the source of the magma. The coal was entirely transformed into decrepitative cinder coal which presents some periodical waves within the sill and occurs in long oriented sack-like pools. The longer axis of the pools appears to intersect the flow direction nearly at right angles. Toward the Ōminé colliery, or as the depth increases, both amount and heat of the intrusion decreased gradually and the degree of metamorphism of the coal is less. In the deepest terminal part the sill forks into several tongues. The magma meandered through the coal seam in the direction of dip as if it flowed through a free space. The metamorphism did not go beyond transforming the coal into low grade cinder coal (fuel ratio less than 6.0 stratification o. the seam still retained), and few effects of fusion metamorphism are found.

For a magma to intrude coal seams, two factors at least are required: 1) an intrusive power strong enough to displace the load of the hanging wall, and 2) a reduction in the volume of coal due to escape of volatile matter and progress of coalification (although increasing porosity makes up to some extent for the volume reduction). When these two factors worked together, the combined thickness of the sill and the metamorphosed coal seam would become always larger than the pre-intrusion coal seam would be much less than the combined pre-intrusion coal seam and sill, as is known from the columnar section of the Oyake 3.5-ft seam.

Commonly a whole coal seam is replaced by a sill. In such a case, even if the seam itself expands due to the formation of bubbles, the volume on the whole is reduced. Due to the heat the coal is fused or becomes plastic, and the contents of the seam are pushed in the direction of the magma's progress, and migrate within the seam, resulting in a "swept up" feature. Then this movement meets resistance caused by solidification of coal as it is converted into coke and solidification of the frontal portion of the magma. The pushing force of the magma in the rear still works, crushing the solidified cinder coal or causing minor thrust faults (fig. 3). The sill front is often convex toward the cinder coal. The magma supplied from the rear of the solidified igneous rock ascends toward the hanging wall and flows through the boundary [between the hanging wall and the coal seam], and then flows down into the coal seam again. When it reaches the uncoked part of the coal, it fuses the coal. Thus, the sill increases in thickness, and gradually descends until it reaches the foot wall where it may repeat the sweeping and solidification processes. Repetition of such movement would produce pools of cinder coal having a wave length [T. N.; sic] of 20 to 30 m or even longer. Once fused, the coal is often transformed into mate.[4]

Such mode of intrusion as mentioned above is usually recognized in coking coals. In non-coking or weakly coking coals, like that of Tenjonashi seam of Mineji, the fluid movement of magma seems to have been restricted. That is to say, sills do not extend in the dip direction or do not spread to the limit the geologic structures permit. The magma intruding coal seams through fissures would meet considerable resistance, because even when the coal is thermally altered it is not fused but is only pulverized within small areas. Hence, the magma can move only when its pressure surpasses the resisting force. In this case, a mass of sill can be formed only near the fissure which served as a supply route, and from there the sill forks into several arms that generally extend parallel. Between such parallel arms are developed another kind of intrusive sills consisting of powder coal (cinder coal) resulted from scraping by the solidified igneous rock, fragments of parting, and volcanic gravel. These sills of igneous rock and powder coal constitute a series of intrusive bodies that move around within the coal seam concordantly or, to some extent, discordantly (fig. 2). In short,

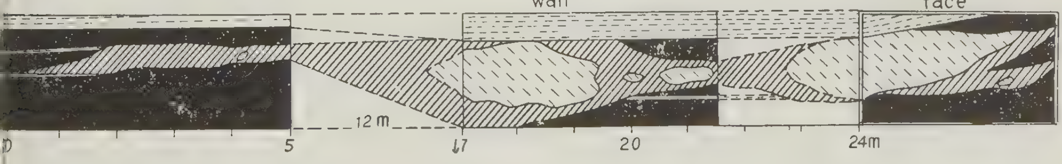

FIGURE 2. Ends of sills of andesite and decrepitative cinder coal in the Tenjonashi seam, showing the leftward advance of flow

- Tenjonashi seam, with cinder coal at zone of contact

- Hard cinder coal resulted from welding of powdery coal

- Shale. - Bouldery or club-like andesite.

[4] T.N.: "Mate" is a miner's term for natural coke showing quadrangular or hexagonal columnar joints. The author in his English summary calls it "columnar cinder coal."

where the coal is too hard to be fused in heat, although it may be pulverized, the supply of magma would not be made smoothly, so that the sill near the supply source becomes thicker, whereas the portion distant from the source becomes thin, or is broken into small blocks, and would migrate together with powder coal. In such a place, cooling and solidification of magma are supposed to be faster, and so the sill arms would move as a solid or semi-solid substance. The igneous rock works as a coal cutter. The tip of the flow consists of thermally altered powder coal containing igneous pebbles, and tapers into a thin wedge of powder coal (fig. 2). Under intense heat and pressure the surface of sill and igneous pebbles is thinly coated by hard cinder coal which is commonly mylonitized. The plane of exfoliation and the surface of the volcanic rock show slickensides with streaks incised in the flow direction. As slickensides are seen also in the convex front of coking coals, the direction of the movement can be known by observing the streaks.

In both coking and noncoking coals, a "coal dike" is often seen to intrude up to a considerably high horizon, cutting the hanging wall vertically or at high angles. The coal dike is composed of cemented aggregates of more or less thermally metamorphosed powder coal and fine fragments of shale, sandstone and igneous rock. Fissures through which this dike intruded appear to be tension cracks. Like some ore veins, coal dikes occur occasionally along the hanging and foot walls of igneous dikes. This indicates that after the powder coal flow associated with the sill, intrusion reached the cracks in the hanging wall. Joints vertical to the sandstone in the hanging wall are sometimes filled with calcite crystals and tar. Tar fills the druses of calcite. These parallel veinlets of calcite and tar are the precipitates resulted from volatilization of coal substances and cooling of the hydrothermal solution. They are found scores of meters apart from the coal seam.

PETROLOGIC CHARACTERS AND DISTRIBUTION OF DIKES AND SILLS

Most igneous rocks, especially dikes, occurring in the underground galleries are whitish. Some are dark gray but are usually encircled by the white part. This feature is known in coal fields of England also, where white rocks are called "white trap." (Raistrick and Marshall, 1939). The white color is due to carbonation. In markedly white portion all mafic minerals were converted into carbonates.

Under a microscope a megascopically gray and fresh specimen of the igneous rock reveals the texture of basaltic olivine-pyroxene andesite. From the combination of phenocrysts, the rock can be divided into two types, A and B, although the difference between the two is small. Such igneous rocks are known in the Shimoyamada mine, Kaho-gun. Igneous rocks in the coal mines of southern Chikuhō coal field are much alike, in both the mode of occurrence and lithology.

Andesite of type A contains phenocrysts of rhombic and monoclinic pyroxene and olivine. Plagioclase is absent. Quartz xenocrysts are commonly present.

Judging from the texture and the paragenic relation of the rock, rhombic pyroxene and monoclinic pyroxene are supposed to have crystallized concurrently. According to the crystallization-relation diagram by Hisashi Kuno (1954), the above-mentioned crystals indicate a low temperature of crystallization. The cause of the crystallization is related to the contents of potassium and volatile matter. Degree of coalification due to heating is governed by the temperature of magma.

Olivine is entirely replaced by secondary minerals and presents pseudomorphs. The secondary minerals are dolomite (ω = 1.692 or larger), and saponite (one specimen showed γ = 1.522, α << 1.508, extinction is straight, extension positive, optical character negative, double refraction marked, X = yellow or colorless, Y, Z = light brown to brown or greenish brown). More metamorphosed parts consist of dolomite and quartz. Rhombic pyroxene is fresh inside the sill, but near the contact it is saponitized and then dolomitized. These facts reveal the alteration processes, i. e., in the central high temperature part the silicates containing no Ca under water influence [T. N.; literal translation] were saponitized, while the marginal part is affected by both water and CO_2 and produced dolomite and quartz (or chalcedony).

The groundmass consists of slender columnar plagioclase (An 73+), biotite, magnetite and intersertal alkali-feldspar and quartz. In a rapidly cooled part the interstices of plagioclase are filled with glass. These groundmass minerals seldom suffered secondary alteration. In other words, they were stable under high temperatures saturated with water and CO_2.

Andesite of type B consists of rhombic pyroxene and monoclinic pyroxene in equal proportion and a very small amount of olivine. The composition [T. N.; content?] of pyroxene is same as that in type A.

The underground distribution of type A and type B varies locally, which may indicate, to a certain extent, the possible route of magma's flow. However, the marked similarity of the two types suggests that two analogous magmas more or less differentiated, have intruded almost contemporaneously.

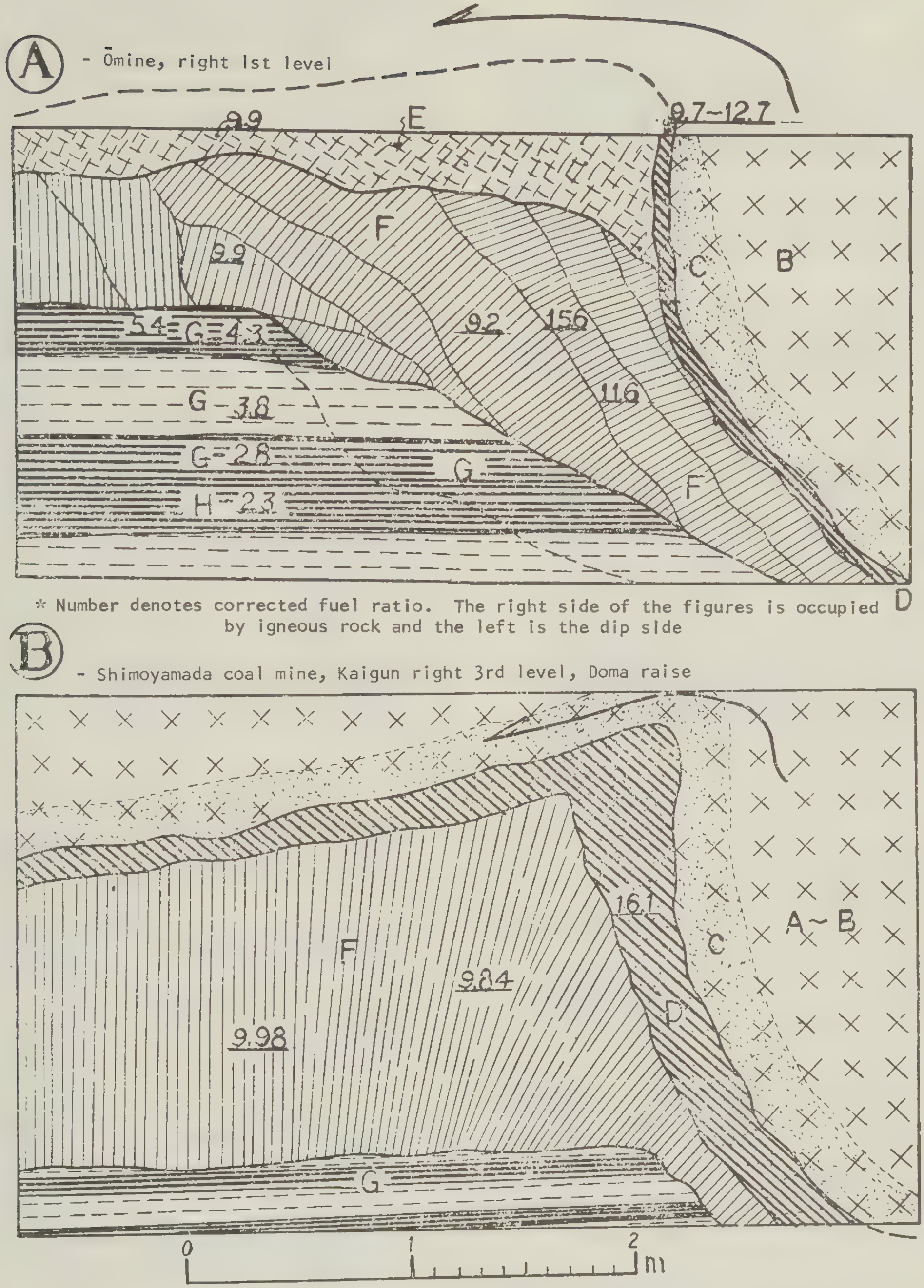

FIGURE 3. Shale and contact metamorphism of a sill in the coking coal

A×B - Andesite A-B zone

×C× - Andesite, C zone

D - Decrepitative cinder coal, D zone

E - Crushed cinder coal, E zone

F - Columnar cinder coal, F zone

G - Low grade cinder coal, G zone (G' is the part with an anthracitic appearance)

G - Coaly shale similar to low grade cinder coal

H - Weakly metamorphosed zone, H zone

THERMAL METAMORPHISM OF COAL BY SILL

The contact-metamorphosed coals (natural coke) of Ōminé and other mines of the Chikuhō coal field decrepitate, when heated, at 300° to 450°C. Those which are hard and adhered to the sill are called hard cinder coal, those having columnar joints are called columnar cinder coal, and those which are stratified and low in degree of coalification are called low grade cinder coal.

The mode of metamorphism thus greatly differs between coking and noncoking coals. Where coking coal is thermally metamorphosed by sill, the zonal arrangement as seen in Figure 3 is generally observed.

The combined thickness of zone D through G is usually about 2 m. In zone C all mafic minerals are dolomitized, and the interstices of the groundmass are filled with a mixture of residual solution of the magma and minute grains of carbon. The carbon content gradually decreases to zone B. The boundary C and D shows the mode of inflow and solidification of molten matter and as well the crushing after solidification. In the andesite near the boundary are many white veinlets consisting chiefly of dolomite accompanied by quartz or chalcedony. Under a microscope carbon grains are seen on both sides of the veinlets and are enclosed by quartz and dolomite. In zone D also are cracks, slickensides and minute pores; the globular or oval pores are filled with dolomite and quartz, occasionally accompanied by calcite. In zones E and F, calcite predominates, associated with some carbonates. Such zones may not be of igneous origin, since calcite is a carbonate formed in cleats of unmetamorphosed coal. In zones D, E, and F, coal is fused and mixed, and fragments of parting are welded with coal to such an extent that they are hardly separable in dressing. Coal in zone D contains dolomite and quartz of hydrothermal origin, besides parting fragments, so that the ash content is very high and an increase of MgO, CaO, SiO_2 and Fe_2O_3 is especially noted. In zones D, E, and F, the fuel ratio calculated from the volatile matter, after subtracting CO_2, is 7 to 12, occasionally attained to 15 or 16. In the zone of low grade cinder coal (zone G) it does not exceed 6, generally 5 or less, hence the boundary between fusable and unfusable coals is supposed to lie around the value of 6. Judging from the result of dry distillation of the coal from the Tagawa 3-ft seam, the contact temperature of the initial coal, ignoring such conditions as the pressure and the degree of coalification which must have differed from the present coal, may have been 550° to 740° C for the fuel ratio of 7 to 15.

Zone	Subzone	Lithology	Thickness
Igneous sill (generally 1 to 2 m thick, sometimes several m)	A. Central zone	Gray saponitized andesite	Boundary irregular
	B. Contact zone	White dolomitized andesite	
	C. Direct contact zone	Grayish black carbon-bearing dolomitized andesite	10 to 50 cm wide
Cinder coal zone (fused zone)	D. Decrepitative cinder coal contact zone	Dolomitized and silicified hard cinder coal	10 to 50 cm wide
	E. Crushed and re-welded columnar cinder coal zone	Gravelly, re-welded cinder coal	Scores of cm wide or less
	F. Columnar cinder coal zone	High grade columnar cinder coal, with low ash content	Generally less than 150 cm
Stratification preserved, thermally metamorphosed zone (unfused zone)	G. Stratified low grade cinder coal zone	Stratified semianthracite and cinder coal	
	H. Weakly metamorphosed zone	Cinder coal (closer to flaming coal) and niggerheads	
Unmetamorphosed zone	I.		

Decrepitation of coal is always proportional to the abundance of globular or oval independent bubbles, or "confined pores" according to Maso Taki (1936), and to the water content as well. Zones D and E are markedly decrepitative.

In general, noncoking coals are seldom transformed into cinder coal. Igneous intrusions would merely cause reduction of volatile matter and pulverization of coal. The outer side of the relatively thin hard cinder coal coating the igneous rock immediately passes into the zone of low-grade cinder coal. The metamorphosed zone is usually narrow. The decrepitating power of the hard cinder coal is generally weak, and few bubbles are seen under a microscope. The fuel ratio of the cinder coal is about 6.

Data on the chemical composition of the metamorphosed coals are here omitted for the sake of brevity.

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ON PRINCIPAL RULES IN THE OCCURRENCE OF OIL AND GAS ACCUMULATIONS IN THE WORLD[1]

by

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• translated by the author •

ABSTRACT

Oil and gas fields of the world are universally associated with downwarping of sedimentary rocks. They occur in three principal types of depressions: 1) platform-plain, 2) piedmont, and 3) intermontane. Seven subgroups of occurrence are recognized. Approximately 130 actual or potential oil and gas basins are delineated in three major mountain belts and two major platform belts. -- M. Russell.

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DEVELOPMENT OF IDEAS ON RULES IN THE OCCURRENCE OF OIL AND GAS ACCUMULATIONS

Some considerations on rules observed in occurrence of oil and gas accumulations appeared early in the science of petroleum and gas. In this connection it is necessary to define the boundaries of the vast oil and gas regions.

Based on the study of Southeastern Caucasus, G. Abich (1847, 1876) suggested that mud volcanos ejecting combustible gases and then known oil fields were associated with fault zones.

Ideas about "oil belts", to which surface oil and gas seepages were related, were widely developed in the middle of the last century in Germany, Rumania and the United States. D. I. Mendeleyev (1877) connected linear oil and gas seepages on the borders of highlands and plain territories with large fractures in the earth crust (faults) along which the oil penetrated from earth depths where, in his opinion, was the center of oil formation.

Attempts to outline oil and gas regions according to geographical location were made in the second half of the last century by Leeds in the United States (1865) and by G. Romanovsky (1877) and S. O. Gulishambarov (1883) in Russia. Somewhat later, in his work on productive zones in Rumania, Mravec (1902) considered location of oil fields in relation to large stratigraphic complexes and tectonic elements of the Carpathians. In Russia the Geological Committee has conducted, for the same purpose, regional geologic studies of productive areas of the Caucasus, Central Asia and Near-Caspian depression.

In his review devoted to geologic features of occurrence of mineral products in the world, De Launay (1913) attempted to outline rules of occurrence of petroleum and bituminous rocks in connection with geotectonic zones. He marked out in particular the areas of Paleozoic, Mesozoic and Tertiary oil and gas accumulation.

In his lectures delivered before the students of Leningrad Institute of Mines, K. I. Bogdanovich considered (1921) the areas of occurrence of oil, gas and bituminous rocks and related their formation with principal periods of earth-crust movement which have determined the formation of new geotectonic elements and the change of existing ones. De Launay and Bogdanovich, unlike other investigators, considered not separate oil and gas accumulations but large zones of these caustobioliths.

The relationship of oil and gas accumulations with large structural elements of North America was shown during 1919-1920 by several geologists, and the term "oil and gas province" was introduced. This term is used by Woodruff (1919), Schuchert (1919), and later on by Lilley (1923) et al., in classifying North American oil and gas provinces on the basis of general geologic properties.

The above mentioned authors have considered as oil and gas provinces large geologic provinces to which numerous oil and gas accumulations were related. In particular, such geotectonic elements as the Rocky Mountains as a whole, all of the central part of the North American platform - Midcontinent, etc., were considered as one province. A more detailed geologic-tectonic demarcation was suggested by Ver Wiebe (1930). Under the term of oil and gas province Ver Wiebe understood, on the one hand, separate large platform depressions of the coal basin type of central part of North American platform and, on the other hand, platform arched uplifts and large structural zones of linear strike.

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I. M. Gubkin considered (1932) the occurrence of oil and gas accumulations on a broad scale. Formulating the principle of oil fields occurrence, he noted that oil fields occur, on the one hand, in peripheral zones and flanks of mountain ranges and, on the other hand, in plain regions composed of thick sedimentary series. Gubkin pointed out that when estimating oil and gas possibilities of large regions, particular attention should be paid to the conditions of sedimentation with a view of identifying those series to which regional oil and gas possibility could be related.

N. Yu. Uspenskaya in a number of publications (1946, 1947, 1952) further developed ideas about oil and gas provinces formulated earlier and work out their classification. N. Yu. Uspenskaya defines this term as follows: "Under oil and gas province is understood a large region of occurrence of oil and gas accumulations possessing a unity of geologic structure and geologic history featured by uniform facies and types of structural elements controlling bitumen formation and oil accumulation." Proceeding from this definition N. Yu. Uspenskaya considers three classes of oil and gas provinces: 1) depressions of various ages, 2) large arched uplifts, 3) groups of uplifts on the slope of large structures etc. Elaboration of this concept and analysis of principles of classification of oil and gas provinces can be found also in publications of this reviewer (Brod, 1944, 1946, 1951, Brod and Eremenko, 1950) devoted to systematization of data characterizing conditions of oil and gas occurrence and especially to development of ideas about oil and gas accumulation zones.

Although the most complete classifications of oil and gas fields as worked out by I. M. Gubkin (1932), F. Clapp (1910, 1917, 1930), E. Blumer (1919) et al. did not distinctly formulate the concept of zonality in the occurrence of oil and gas, their descriptions of separate groups of accumulations contain this concept. Up to 1936 scientists have concentrated attention on the revelation of zonal relationship between numerous oil and gas accumulations and anticlinal zones. A. I. Levorsen formulated (1936) in a most distinct manner the concept of regular zonal occurrence of numerous oil and gas traps on the flanks of large areas of downwarping of the earth crust. At the same time Levorsen contrasted the structural principle of trap formation to that of stratigraphic conditions determining zonal occurrence of traps which make their appearance at lithological wedging out or unconformable overlapping of productive series on their up-dip side. In the U. S. S. R. the role of stratigraphic traps in the accumulation of oil and gas was shown in the works of M. F. Mirchink (1941, 1943)

The principle of division of productive zones into two genetic groups, namely, structural and stratigraphic zones, has justified itself. The zones uniting numerous oil and gas accumulations have been termed "oil and gas accumulation zones" (Brod 1944, 1946, 1951). This term is widely used in Soviet literature (N. Yu. Uspenskaya 1946, 1947; A. A. Bakirov 1948, 1951; M. F. Mirchink 1951; N. B. Vassoevich and V. A. Uspenskiy 1954; V. E. Khain 1954). It may be taken for granted that in most diverse geologic conditions oil and gas accumulations are grouped either as related with large structural uplifted zones or as related with zones of regional wedging out or unconformable overlapping of thick series containing in their sequence highly permeable rocks (Stratigraphic type of oil and gas accumulation).

In anticlinal zones of oil and gas accumulation the synclines adjacent to them serve as oil and gas collecting areas. Consequently, in such structural zones the migration of hydrocarbons usually takes place from two sides. The hydrocarbons coming up to the most uplifted parts of brachyanticlines and domes, which are the components of anticlinal zones, are accumulated in the form of oil (gas) pools either in the arches of anticlines or in traps related to their flanks or periclines.

The case is somewhat different with the migration of hydrocarbons of stratigraphic zones of oil and gas accumulation uniting numerous traps formed on homoclines or monoclines in connection with regional lithological wedging out or unconformity. Hydrocarbons coming up the regional dip accumulate in separate traps of diverse form grouped along the edge of wedging out or unconformable overlapping of reservoir beds. The feeding here is one-sided: the adjacent down-dip parts of homo- and monoclines serve as oil and gas collecting areas.

When revealing the regularities in the occurrence of oil and gas accumulations one problem is of great importance, that is, the correlation of zones of oil and gas accumulation. Pratt (1942) and Gester (1944) noted that a quite regular pattern of oil and gas accumulations exists and that the principal areas of oil and gas are related to those parts of the earth's crust which experienced the strongest downwarping accompanied by extensive accumulation of sediments. To elucidate this, a scheme of oil and gas regions and possible oil and gas regions of the world has been compiled. Analysis of this scheme led to a formulation of basic law of oil and gas accumulation (Brod 1947, 1951). The essence of this law lies in the fact that the accumulation of oil and gas is determined mainly by the scale and duration of subsidence of the earth crust area under review as well as by the degree of burial of the pools. A preponderance of subsidence over uplift in the course of oscillating movements of the crust favors the processes of bitumen formation and oil and gas accumulation.

Further analysis has shown that all known oil and gas accumulation zones are elements of large enclosed areas of subsidence in the actual structural pattern of the earth crust. Obviously, such an occurrence of oil and gas accumulations is not accidental and it is connected with the fact that oil and gas pools are related to local traps which are small elements of large water-drive systems. Present theory holds that oil and gas filling the traps are in equilibrium with water filling highly permeable rocks which serve as natural reservoirs for mobile substances. Consequently, the study of regularities in correlation between water, oil and gas should be conducted separately for each lithological-stratigraphic complex which may be considered as one water-drive system. Equilibrium of oil and gas pools in water-drive systems depends largely on the intensity and direction of water flow which are determined by position in relation to intake and discharge areas. It may be taken for granted that formation and destruction of oil and gas pools are determined mainly by regional hydrogeological environment.

The regular relationship between known zones of oil and gas accumulation and different large regions of subsidence in the actual structural pattern of the earth crust has served as a basis for considering such depressions as oil and gas basins (Brod, 1953). This concept is widely accepted in Soviet geologic literature on petroleum and gas.

Each oil and gas basin is a vast artesian system. A number of regionally productive series, each a water-drive complex, enters in composition of the basin. Although each of these water-drive complexes differs from the other, still, viewed as a whole, they are the elements of one artesian system. Consequently, the study of oil and gas basins should necessarily be divided into the study of separate regionally productive series and that of the system or basin itself taken as a whole.

Regularities in the occurrence of oil and gas basins in the world are determined by their affiliation to large geotectonic zones.

PRINCIPLES OF CLASSIFICATION OF OIL AND GAS BASINS

In order to detect regularities in the occurrence of oil and gas accumulations in the world an attempt has been made to outline all known and main possible future oil and gas basins (Brod, 1953). On the basis of geotectonic location and geological and geomorphological features, some principles of classification of oil and gas basins were suggested at the same time. Later a map of oil and gas basins of the world was compiled (Brod, 1957).

Revision of data on structural patterns of oil and gas basins has permitted further refinements of the compiled map (see figures 1, 2, 3, 4, and 5).

When studying features of oil and gas basins one should always bear in mind the possibility of estimating their relative oil and gas possibilities. Such is possible only if all the changes undergone in the area under review in its geologic history is taken into consideration. Whether the relations between reservoir rocks of high permeability and poorly permeable ones - pelitic rocks - were most favorable for oil and gas accumulation, - this factor can be determined only if there is adequate knowledge of the changes of thickness and lithological composition of sedimentary series forming the basin. However, regardless of the changes in the present area of oil and gas accumulations has undergone in its geological past the fundamental condition required for oil and gas accumulations is the existence of a clearly defined region of downwarping. Such a presumption derives from the fact that the formation of elementary-isolated accumulations which are entering in composition of oil and gas accumulation zones takes place in the process of migration and differentiation of mobile substances in highly permeable reservoir rocks. Formation and preservation of each elementary accumulation is possible only in a trap preventing the escape of oil and gas. Consequently, the regular occurrence of oil and gas accumulation zones in each basin is controlled first and foremost by its structure and geomorphology, factors which govern the subsurface water-drive intensity and direction.

In consideration of all these features, the structural-geological and geomorphological properties were assumed as a basis of classification of oil and gas basins. Geomorphology is of great importance, as the direction of migration substances entering the several reservoir beds of any given sedimentary series in a basin depends to a large extent on surface relief of the depression as well as the surface relief of the margins of the depression.

Thus, the combination of geomorphological and geotectonic properties is assumed as a basis of classification of oil and gas basins. Taking into consideration all possible combinations, all known enclosed areas of subsidence of the earth crust have been divided into three principal groups (table I).

Basins of platform plain depressions belong to the first group. In this group are all plain regions of subsidence geotectonically related to areas in the platform stage of development. These basins are bordered more commonly by slopes of platform arched uplifts as well as by buried uplifted zones of linear strike separating the basins. Nearly levelled pre-Tertiary folded mountain structures border some basins for relatively short distances.

In the second group of oil and gas basins

FIGURE 1. Oil and gas basins of the West Pacific Mountain Belt.

LEGEND (For figures 1-5)

- Oil and gas basins formed in platform (plain) depressions with Precambrian basement
- Oil and gas basins formed in platform (plain) depressions with Paleozoic basement
- Oil and gas basins formed in platform (plain) depressions with basement rocks of various ages and complex structure
- Oil and gas basins formed in piedmont depressions of Paleozoic folded zones with one well-pronounced mountain flank
- Oil and gas basins formed in piedmont depressions of Mesozoic folded zones bound by one well-pronounced mountain flank, or piedmont depressions of Cenozoic folded zones
- Oil and gas basins of intermontane depressions formed on basement of median massifs or their large elements
- Oil and gas basins of intermontane depressions formed on separate downwarpings or local grabens

WEST PACIFIC MOUNTAIN BELT

A. Group of East Asiatic basins related to Mesozoic folded belt:

A/I. Northern Verkhoyansk subgroup:
1. Lena-Vilyuy
2. Kolyma

A/II. Peri-Baikal subgroup of small basins

A/III. Subgroup of Mongolian and Peri-Amur basins
4. Zeya-Bureya
5. Trehrechye
6. Mongolian
7. Sungliao

A/IV. Subgroup of Huanghe-Yangtze river basins:
8. Ordoss (Shensi)
9. Haihuang
12. Szechwan
13. Yangtze River

A/V. Subgroup of South China basins:
14. Tonkin
14a. Kwangsi-Kweichow

(Continued on next page)

WEST PACIFIC MOUNTAIN BELT (Concluded)

B. Group of basins of East Asia, Indonesia and Oceania principally related to the folded belt of peninsular and insular arcs.

B/I. Northern (Far Eastern) subgroup:
- 3. Far Eastern
- 3a. Central Kamchatka and East Kamchatka
- 3b. Anadyr

B/II. Middle subgroup of Japanese and Chinese basins:
- 10. West Japanese
- 11. East Japanese
- 15. Taiwan

B/III. Southern (Indonesia-New Zealand) subgroup:
- 16. Indonesian
- 17. Vogelkop
- 18. Arafura
- 19. North New Guinea
- 20. New Caledonian
- 21. New Zealand

are all piedmont regions of subsidence of the earth crust. Basins of this group are borded on one blank by folded mountain structure and on the other flank by the plains of a platform slope.

In the third group of oil and gas basins are all possible intermontane depressions most diverse as far as their geotectonic location geological pattern and history of geological development is concerned.

Further division of the basins of the first two groups into subgroups is based on the age. Plain platform basins are subdivided depending on the age and structural pattern of their basement, while basins of piedmont depressions - depending on the age of their folded flank. The subdivision of basins of intermontane depressions is made according to their tectonic features.

OIL AND GAS BASINS OF PLATFORM PLAIN DEPRESSIONS

Oil and gas basins of platform plain depressions cover the vast areas which generally exhibit the gentle regional dips of the beds comprising the basin. Only a small part of the geological sequence is exposed at the surface and consequently the areas of water penetration from surface into depth are rather small. Oil and gas accumulations are related to sedimentary series of rocks formed during the platform stage of development of the earth crust area under review. In metamorphic or crystalline rocks of platform basement which passed geosynclinal state of development, oil and gas accumulations are revealed only at their penetration from unconsolidated rocks mantling the basement. The formation of structural zones of different type and separate uplifts in sedimentary rock series is related in the main to differential movements of basement blocks.

TABLE I. A Classification of the Oil and Gas Basins of the World

Oil and gas basins of:

I. Platform plain depressions
- a. Precambrian basement
  - Examples:
    - Moscow
    - Michigan
    - Lower Amazon
    - West African
    - West Australian
- b. Paleozoic basement
  - Examples:
    - English-Parisian
    - West Siberian
- c. Basement rocks of various ages and complex structure
  - Examples:
    - North Caspian
    - Gulf of Mexico

II. Piedmont depressions
- a. Paleozoic folded zones bordered by one well-defined mountain flank
  - Examples:
    - Pechora-Tuman
    - Taymir
    - Appalachian
    - South African
    - Mid-Australian
- b. Mesozoic folded zones bordered by one well-defined mountain flank; Cenozoic folded zones
  - Examples:
    - Fore-Alpine
    - West Black Sea
    - Middle Caspian
    - Karakum
    - Persian Gulf
    - Lena-Vilyuy
    - Western Canada
    - Eastern Venezuela
    - Arafura

III. Intermontane depressions
- a. Formed on median massifs or their large elements
  - Examples:
    - Pannonian
    - North Italian
    - South Caspian
    - Central Iranian
    - Tarim
- b. Formed on separate downwarpings or local grabens
  - Examples:
    - Rhine
    - Chuya
    - Burma
    - Japanese
    - Rocky Mountains
    - Colombia
    - Egyptian
    - New Guinea

EAST PACIFIC MOUNTAIN BELT

A. Group of North American Subcordillera basins.

A/I. Northern subgroup of Subcordillera basins:
22. North Alaska
27. Western Canada
28. Willistone

A/II. Southern subgroup of plain Subcordillera basins with basement of different age:
30. Western Interior
31. Permian
32. Gulf of Mexico

B. Group of North American intermontane basins.

B/I. Subgroup of intermontane basins of Rocky Mountains:
29. Basins of Rocky Mountains

B/II. Subgroup of West Cordillera basins:
23. South Alaska
24. San Joaquin
25. Cuyama
26. West California

C. Group of South American Subandean basins.

C/I. Northern subgroup of Subandean basins:
40. East Venezuela
41. West Venezuela

C/II. Middle subgroup of Subandean basins:
43. Upper Amazon
45. Central Subandean

C/III. Southern subgroup of Subandean basins:
46. Mendoza
47. Neuquen
48. Patagonia
49. South Subandean

D. Group of Central American and South American intermontane basins of young folded structures.

D/I. Subgroup of intermontane basins of Carribean sea regions:
33. North Cuba
34. South Cuba
35. Haiti
36. Panama
37. Columbia
38. Maracaibo
39. Tocuyo River

D/II. Subgroup of west South American intermontane basins:
42. Guaquil
44. Titicaca

FIGURE 2. Oil and gas basins of the East Pacific Mountain Belt

(See Figure 1 for Legend)

FIGURE 3. Oil and gas basins of the Latitudinal Mountain Belt of the Eastern Hemisphere

LATITUDINAL MOUNTAIN BELT OF THE EASTERN HEMISPHERE

A. Group of basins of the western part of the belt.

A/I. Subgroup of piedmont basins of the Pyrenees, Alps and Carpaths:
50. Aquitanian
55. Languedoc
58. Subalpine
65. Subcarpathian
66. West Black Sea

A/II. Subgroup of intermontane basins:
51. Ebro River
52. New Castilian
53. Portuguese
54. Guadalquivir
56. North Italian
57. East Italian
59. Vale Latina
60. Albanian
62. Vienna-Moravia
63. Pannonian
64. Transylvanian
67. Thracian

A/III. Subgroup of basins of Atlas Mountains and contiguous maritime regions:
61. Sicilian
89. West Morocco
90. North Algeria
91. Middle Algeria
92. Tunis

B. Group of basins of the middle part of the belt.

B/I. Subgroup of piedmont basins of Crimea, Caucasus and Kopet-Dag:
68. Azov-Kuban
69. Middle Caspian
72. Kara-Kum

B/II. Subgroup of intermontane basins:
70. East Black Sea
71. South Caspian
73. Central Iranian

B/III. Subgroup of piedmont basins of Taurus and Zagross:
87. East Mediterranean
88. Persian Gulf

C. Group of basins of the eastern part of the belt.

C/I. Subgroup of intermontane basins of the eastern part of Middle Asia:
74. Chuya
75. Ferghana
76. Tajik
77. Ili
77a. Issyk-Kul

C/II. Subgroup of intermontane basins of Central Asia:
78. Tarim
80. Dzyngarian
81. Turfan
82. Subnanshan
82a. Chaoshuy
82b. Mingho
83. Tsaidam
83a. Thibet

C/III. Subgroup of Himalaya basins:
79. Pakistan
84. Assam
85. Bengal
85a Subhimalayan
86. Burma

(See Figure 1 for legend)

FIGURE 4. Oil and gas basins in the North Platform Belt

A. Group of North American basins related to the slopes of Canadian shield.

A/I. Subgroup of plain platform depressions with Precambrian basement:
115. Illinois (Eastern interior)
116. Michigan

A/II. Subgroup of piedmont depressions of Paleozoic folded structures:
117. Appalachian

A/III. Subgroup of intermontane depressions of North American Caledonides:
118. Eastern Canada

B. Group of European basins related to the slopes of Baltic shield and region of Paleozoic folded structures of Western Europe.

B/I. Northern West European subgroup of intermontane basins of graben type:
93. Scottish
94. West England

B/II. Subgroup of West European plain platform basins with basement of different age:
95. English-Parisian
99. Peribaltic

B/III. Southern West European subgroup of intermontane basins of graben type:
96. Liman
97. Rhine
98. Thuringian

B/IV. Subgroup of plain platform basins of the Russian platform with Precambrian basement:
101. Middle Russian

B/V. Subgroup of basins of the Russian platform with basement of different age:
100. Pechora-Tuman
102. Dnieper-Don
103. North Caspian
104. Sylva

C. Group of Siberian and Middle Asia basins.

C/I. Subgroup of Siberian basins with basement of different age:
105. West Siberian 106. Taymir

C/II. Subgroup of Siberian plain platform basins with Precambrian basement:
107. Tunguska 111. Rybinsk
112. Irkutsk

C/III. Subgroup of Siberian intermontane basins with Paleozoic basement:
108. Tenghiz. 109. Kuznetsk. 110. Minusinsk

C/IV. Subgroup of Middle Asia plain platform basins with basement of different age:
113. Ust-Urt 114. Khizil-Kum

(See Figure 1 for legend)

FIGURE 5. Oil and gas basins in the South Platform Belt

A. Group of South American basins related to large depressions of the Brazilian platform:
- 119. Lower Amazon
- 120. East Brazilian
- 121. Parana

B. Group of African basins related to large depressions and faults of African platform.

B/I. Northern subgroup:
- 122. Sahara

B/II. Western subgroup:
- 124. West Africa

B/III. Southern subgroup:
- 125. South African

B/IV. Eastern subgroup; principally intermontane basins of graben type related to the faults of African platform:
- 123. Egyptian
- 126. Madagascar
- 127. Somaly

C. Group of Australian basins.

C/I. Subgroup of platform and piedmont basins:
- 128. West Australian (Carnarvon)
- 129. Middle Australian

C/II. Subgroup of intermontane basins:
- 130. South Australian (Gippsland)

(See Figure 1 for Legend)

Platform plain basins are divided into three subgroups. The first subgroup includes basins with Precambrian basement; the second, the basins with Paleozoic basement; and the third, the basins with basement of various ages and complexly built (table 1).

The basins of platform plain depressions with Precambrian basement are usually related to central parts of present platforms (figs. 1, 2, 3, 4, 5). As a rule the thickness of sedimentary series forming these basins does not exceed 2,000-4,000 meters. Productive series of these basins are in the main related to Paleozoic deposits.

The basin of platform plain depressions with Paleozoic basement are related to the borders of ancient platforms or to young platforms located between ancient platforms. Productive series are related to unconsolidated deposits of upper Paleozoic and Mesozoic age.

Oil and gas accumulation zones of platform plain basins with Precambrian and Paleozoic basement are usually related to platform uplifted ranged (ridges) connected with structural terraces and areas of wedging out and discordant overlapping of reservoir beds on homoclines. Oil and gas accumulation zones are usually located on the flanks of the basin, on the slopes of internal arched uplifts and also over buried ranges (ridges) complicating central parts of the basin.

The basins of platform plain depressions with basement of various ages and complexly built are as a rule related to marginal parts of ancient platforms or to young platforms (table 1, figures 1, 2, 3, 4, 5). Regional productive series in the basins of this subgroup are related to Paleozoic and Mesozoic and occasionally Tertiary deposits. The maximum depth to basement in central parts of these basins reaches 10, 000 meters and more. Stratigraphic interval of actual and possible oil and gas productivity is different in various parts of the basin. Oil and gas accumulation zones are usually related to various structural complications on the flanks of the basins and to buried arched uplifts and ridges complicating central parts of the basins. Oil and gas accumulation zones with salt dome structures are frequently encountered in these basins.

The examination of Figures 1, 2, 3, 4, 5 shows a wide occurrence of the basins of the first group on platform territories of Eurasia and North America. Basins of this type, but usually of a small size, are known also in South America and Australia. In Africa the potentially rich Sahara oil and gas basin belongs to this group.

Oil and gas basins of platform plain depressions with basement of various ages and complexly built are of particular importance as far as oil and gas production and reserves is concerned. In North America this subgroup is represented by the basins of the Gulf of Mexico, Permian and Western Interior; in Europe, by the North Caspian and Peribaltic [along-the-Baltic] basins.

OIL AND GAS BASINS OF PIEDMONT DEPRESSIONS

Asymmetry is a characteristic of oil and gas basins of piedmont depressions; it affects in particular the formation of water-drive intensity. The basins of this group are bordered on one side by a narrow relatively steep flank commonly represented by frontal folds of folded mountain structure bounding the basin. The other flank of the basin is a plain usually related to a vast platform homocline complicated only by structural terraces and gentle platform anticlines.

As regards to the basins of piedmont depressions of Paleozoic and Mesozoic structures it is emphasized in the appended scheme of classification that only basins possessing one strongly pronounced mountain flank, which determines the intensity of water-drive and direction of subsurface water movement, are referred to this group. The necessity of this limitation lies in the fact that Mesozoic and especially Paleozoic folded structures are often leveled to such an extent that they lose their mountainous nature. Basins formed on the basis of piedmont depressions of leveled folded structures lose their fundamental characteristic property - asymmetry - in morphological expression of the bordering and are referred to the group of platform plain basins. The Dnieper-Don basin on the Russian platform may serve as an example of such platform plain basin. It was a piedmont downwarping of Paleozoic structure eroded to base level, represented in the west by the Ukrainian crystalline massif and in the east by frontal folds of the Donbass.

The thickness of the series composing the basins of piedmont depressions reaches 5,000 or 10, 000 meters in areas of greatest subsidence of the basement usually located close to the folded flank of the basin.

The age of productive series in piedmont basins of Paleozoic structures is mainly Paleozoic; that of Mesozoic structures, Mesozoic and that of Cenozoic, Tertiary and Mesozoic.

The conditions of formation and preservation of oil and gas accumulations on platform flanks of the basins of piedmont depressions are similar to those existing in platform plain basins.

The formation of oil and gas accumulation zones on folded flanks of piedmont basins is characterized by a number of specific features in view of the fact that these zones were formed either during the geosynclinal stage of development or following its completion. During the

geosynclinal stage of development the burial and transformation of organic matter took place in the conditions of fast accumulation of thick series among which clastic components were prevalent. Great thickness and depth of plunging provoked a considerable increase of temperature and pressure which accelerated the dissociation of organic matter and formation of bitumens. Great static load of thick series and active tectonic processes facilitated the migration of mobile substances. Numerous and most diverse as to their scale disturbances in the rock completeness favored extra-reservoir migration through thick series of rocks. Frequent and considerable fluctuations of the base levels of erosion and of the bottom of depression led to sharp changes of facies in time and space and, consequently, to the changes in conditions of transformation of organic matter and accumulation of reservoir beds. Frequent dislocations in the regions of maximum downwarping, formation of new structural uplifts and depressions led to dislocation of oil and gas collecting areas. Water circulation and processes of migration occasionally destroyed previously formed oil and gas pools.

Oil and gas accumulation zones located on folded flank of the basins of piedmont depressions are, as a rule, connected with strongly pronounced structural forms and are related to large frontal anticlines of folded structures. Side by side with this, stratigraphic traps are encountered. The formation of these zones is determined by wedging out of reservoir beds or their overlapping on the surface of unconformity.

The group of oil and gas basins of piedmont depressions is divided into two subgroups. The first includes the basins of piedmont depressions of Paleozoic structures; the second group includes basins of piedmont depressions of Mesozoic and Cenozoic structures (table 1).

The majority of known basins of this group is associated with piedmont depressions of Cenozoic and partly Mesozoic structures. Sedimentary series composing the basins of this subgroup are represented in the main of Mesozoic and Cenozoic deposits.

In the eastern hemisphere belts of piedmont basins constitute the north and south borders of the young folded mountain structures of Erasia. In the north these basins are: Aquitanian, Languedoc, Fore-Alpine, Azov-Kuban, Middle Caspian, Kara-Kum, etc., and in the south, the Persian Gulf, Pakistan, Bengal basins, etc. In the western hemisphere the belts of piedmont basins constitute the east borders of the Rocky Mountains in North America and the Andes in South America. The Western Canada and Williston basins are located in North America, and the Western Venezuelan, Eastern Venezuelan, Upper Amazonian and Parana basins are in South America.

Very few basins can be referred to the subgroup of basins of piedmont depressions of Paleozoic folded structures. This is connected with the fact that a great majority of piedmont depressions of Paleozoic folded structures entered in composition of platform territories characterized presently by plains relief.

Such piedmont depressions as the Pechora-Tuman bordering the northern Urals in the U.S.S.R. and Fore-Appalachian in the United States can be referred to piedmont oil and gas basins of Paleozoic folded structures. Apparently, South African and Middle Australian basins, which are insufficiently studied, belong also to this subgroup.

OIL AND GAS BASINS OF INTERMONTANE DEPRESSIONS

The common feature of the group of oil and gas basins of intermontane depressions is that they are bordered on all sides by mountains of different origin and age both folded and block. The conditions of sedimentation, formation of bitumen and oil and gas accumulations in marginal parts of intermontane oil and gas basins bear usually features similar to those of piedmont basins; whereas in central parts features similar to those of platform plain basins.

It is not advisable to subdivide intermontane basins, like platform and piedmont basins, according to age. The final uplift of mountain elements bordering these basins and final subsidence of basins' depressions which have determined their location in actual structural pattern of the earth crust took place everywhere during Cenozoic time. Consequently, age is not taken as a basis of subdivision of intermontane basins, but one of the main features of their tectonic nature determining their internal structural pattern. The basins of intermontane depressions are subdivided into two subgroups. The first subgroup - basins of intermontane depressions formed on median massifs or their large elements; the second subgroup - basins of intermontane depressions formed on separate downwarpings or local grabens.

The thickness and age of series composing the basins of both subgroups range considerably, for their tectonic nature and history of formation of the bordering areas are diverse.

The basins of the first subgroup, i. e. formed on the median massifs and their large elements, occur widely in Central and Eastern Asia. Examples are the Tarim, Tsaidam, Szechuen, Ordos and other basins. In the Mediterranean geosynclinal region the following basins are referred to this subgroup: in Europe,

the North Italian, Pannonian, Transylvanian, East Black Sea basins; in Asia, the South Caspian and Central Iranian basins. In South America, the rich Maracaibo basin belongs also to this subgroup.

Intermontane basins of the second subgroup which formed on the separate downwarpings or local grabens, occur also very widely. In Europe the Rhine and Vienna-Morava basins refer to this subgroup. In Asia, in connection with general large uplift, such basins as Chuya Ily, Tajic, Turfan, Fore-Nanshan, etc., have been formed. In North American a belt of similar basins lies in the Rocky Mountains. In the Andes of South America, the Colombian and Titicaca basins belong to this subgroup. Moreover, as it is mentioned above, Cordilleran folded structures in North American and Andean folded structures in South America are bordered in the east by belts of piedmont basins. In the west these folded structures are bordered by a more interrupted but sufficiently well traceable belt of intermontane basins formed on separate downwarpings. This belt, associated with the fault zone extending along the Pacific Ocean, is represented in North America by the South Alaskan and West Californian basins and in South America by the Guyaquil basin.

CONCLUSIONS

Using the above classification an attempt has been made to plot on the appended maps (figures 1, 2, 3, 4, 5) all known and main possible future oil and gas basins of the world. In conformity the proposed classification all basins are divided into three principal groups and the latter into subgroups.

Analysis of the maps shows a quite regular occurrence of basins related to large geotectonic elements of the earth crust. Large geotectonic zones possess complex geological structures and along their strike they are differently expressed in the relief. Consequently, within the bounds of one and the same geotectonic zone basins of different groups are frequently encountered.

The main purpose of the investigations which were undertaken was the systematization of geological data characterizing the geotectonic nature of oil and gas regions of the world.

With further accumulation of data, the areas, characteristics and classification group of separate basins will probably require a more precise definition and revision.

The outlining of basins' borders clearly shows the regular relationship between oil and gas accumulations and large enclosed regions of subsidence in thick series of sedimentary rocks, as well as of quite a regular occurrence of oil and gas basins related to large geotectonic elements of the earth crust.

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LETTER TO THE EDITOR

In response to your open letter in GeoTimes (vol. 4; no. 7, p. 27) please allow me to make the following comments on the translations of Soviet Geology.

No doubt, AGI had the best intention of starting the project. However, in the present form translations such as of "Izvestiya" and "Doklady" of the Academy of Sciences of the U. S. S. R. are not likely to serve the purpose well because of inaccuracies, wrong terms, excessive length, etc. It may sound strange that inaccuracies result largely from faithful literal translation, but it is true. A great many expressions, especially terms, cannot be translated literally.

"Maykop deposits" is equal to saying Morrison or Dakota deposits instead of Morrison or Dakota Formation. The term stands for a stratigraphic unit (Lower Oligocene to Lower Miocene inclusively). Hence, Formation should be used instead of deposits. Soviet geologists use over a hundred local stratigraphic units for which no English equivalents exist. Consequently, translators and editors obviously select substitutes from several possible or even impossible ones, or translate literally. No improvement can be expected as long as no time table is worked out including these small units. The Russian stratigraphic division is about as follows:

Stratigraphic unit	In Russian means:
Era Period	The same as in English.
Otdel (Division)	May mean Upper, Middle, Lower... but also epoch (Eocene, Oligocene, etc.). Sometimes, also "Podotdel" (subdivision) is used.
Vek (Age) Yarus (Stage)	Usually conformable complex of layers of identical age and containing, if any, almost synchronic fauna and microfauna.
Podyarus (Substage) Seriya (Series) Zona (Zone)	A group of "Svita"s whose chemical and mineral compositions are closely similar or connected by gradual transitions.
Svita (Suite) Sloi (Layers) Otlozheniya (Deposits)	A group of conformably lying beds of closely related composition and deposited under identical conditions.
Gorizont (Horizon) Plast (Bed) Sloy (Layer)	A bed or a few beds with identical fauna and of closely related composition. Not necessarily homogenous in composition; may enclose different lenses, thinner beds, etc.

All three, Podyarus, Seriya, Zona can be translated as substage, while for Svita, Sloi, otlozheniya - instead of which also rock names such as limestones, sandstones, etc. can occur - formation is the most suitable term. Since the terms are vaguely used, depending on the necessity of subdividing a stratum of a certain age and region into more or few units, a unit of smaller division of one region may coincide with one of the higher or even second higher divisions or overlap parts of several higher units of another region.

"Tectonic processes of Variscian time generated the tectonic of the Urals." Tectonic in English means a process but in Russian its result. The proper translation is, therefore, "Variscian (Upper Paleozoic) tectonic formed the structure of the Urals."

"Primary deposit" in Russian means rock deposit of any form (vein, bed, pipe, stockwork, etc.) and any origin (magmatic, sedimentary, metamorphic, but not placer) and should not be translated literally.

"Secondary" in Russian may mean weathered, redeposited, superimposed, epigenetic, etc., and should be so translated, whichever is the case.

"Sub-Moscow Basin" is used in Russian because of its position below Moscow on maps. Basin-south-of-Moscow is its meaning.

"Deluviy" and Diluviy" of Russians have quite different meanings and none should be translated "diluvium."

"Debyeogram" - powder diffraction pattern is the English term.

"Involute of a layer line" - Weissenberg photograph or moving-film diffraction pattern is the English term.

These are a few examples of errors resulting from a literal translation. Hundreds of them occur in the issues I have looked over, especially in "Izvestiya" in which even simple cases such as elongation instead of strike, plunge instead of dip, chamber instead of camera can be found.

The majority of Russian authors use too many unnecessary words, repeat the same statements numerous times, describe at length facts known even to undergraduate students, and bring together Russian and English terms as if they meant different things like branches and apophyses. Omitting unnecessary words would improve translations. For instance, a literal translation follows: Barium titanate monocrystals of perovskite type, the chemical formula of which is $BaTiO_3$, are characterized by tetragonal symmetry, if one considers their fine crystal structure below the temperature of the phase transition that takes place at the Curie point." All this can be said briefly: "Barium titanate is tetragonal below the Curie point."

I recently translated a paper whose content should have been about five pages. However, diluted with long statements and excessively detailed descriptions repeated 17 times (for 17 rock varieties) the paper ran to 55 pages. One learns from the details that quartz contain gas inclusions and shows waved extinction, that chlorite is pleochroic, etc. - facts known to occur everywhere.

Besides, many Russian authors use terms very carelessly such as metallized instead of metal plated; isomorphous phase transition, instead of polymorphous phase transition; terrigenous, instead of clastic, etc. These terms make translations hardly understandable.

American geologists are people pressed for time. They cannot puzzle over Russian idioms and unusual terms, nor read unnecessarily long descriptions of well-known facts, numerous repetitions, etc. What they need is the data, brief and clear sense of new ideas and concepts and the new techniques used or developed. These cannot be given in the usual brief abstract, but in a somewhat expanded annotated bibliography with principal tables and figures attached. Such bibliographies would permit AGI to cover a much greater number of Soviet publications, save time and expense, make the Soviet geological data easily available to American geologists and, consequently, increase the number of persons interested in the AGI publications of Soviet geology.

Regardless whether AGI continues cover to cover translations or restricts straight translations to a few selected papers, a review by a competent geologist familiar with proper usage of terms in both languages is most desirable prior to printing. Even the best editor, without adequate knowledge of Russian, cannot ascertain what the author wanted to say and improve a clumsy sentence and inaccurate terms aggravated still further in the translation.

Please accept my sincere regards and best wishes to you and your staff. I am well aware of how hard it is to get a good translation from the Russian, particularly in the field of geology. Editing the translations undoubtedly requires even greater effort since many of them seem to be prepared by people with little, if any, knowledge in geology, especially in the Russian usage of geological terms.

Salih Faizi
209 Dyckman St.,
New York 40, N. Y.
19 July, 1960

Reference Section

RUSSIAN AND EAST EUROPEAN GEOLOGIC ACCESSIONS OF THE LIBRARY OF CONGRESS

This section is devoted to a listing of selected geologic items appearing in the two publications of the Library of Congress: Monthly Index of Russian Accessions, and East European Accessions Index. These lists are intended as a means of indicating to researchers in the earth sciences some of the material most recently available for screening, further review, and translation. For this reason the lists do not include material now, or soon to be, published in English. Emphasis is placed on Russian material; the extent to which items from East European sources are listed depends on the country and language involved.

A major function of the AGI translations program is the screening of foreign literature for material that should be made available to the English-speaking scientist. Researchers who need such material are urged to review these lists and send us their recommendations for consideration by the editors; the translation needs of all geologists will be served better thereby.

-- Managing Editor

MONTHLY INDEX OF RUSSIAN ACCESSIONS

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RT A—MONOGRAPHIC WORKS

12. GEOGRAPHY & GEOLOGY

AKADEMIIA NAUK SSSR. Institut geologii i razrabotki goriuchikh iskopaemykh. [Materials on the geology of oil potentials of the Kuznetsk Basin] Materialy po geologii i neftenosnosti Kuznetskogo basseina. Moskva, Izd-vo Akad. nauk SSSR, 1960. 269 p.

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____ ____ ____[Graphs] Grafiki.

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- Ney, R. Buried hills in petroleum geology. p. 143.
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- Ramovic, M. Notes about historical data concerning examinations of fallen meteorites (and found) on the Yugoslav territory. p. 273.
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- Jeremic, M. Determination of a contact line of iron-bauxite ore 30 km in length in eastern Bosnia. p. 297.
- Jurkovic, I. Cassiterite, stannite, and molybdenite in ore deposits at Vrtlasce, near Fojnica. p. 309.
- Mitrovic, M. A review of the article "Chrysotile Asbestos at Bosansko Petrovo Selo." p. 321.

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- Bonaci, B. Rapid methods for the determination of materials on the terrain. p. 90.

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- Boskov-Stajner, Z. Outline of N. N. Subbotin's method of selecting microfauna and other methods. p. 42.
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